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CORROSION CONTROL OF PILINGS IN SEAWATER: BUZZARDS BAY.(U)
JAN 81 A KUMAR, R LAMPO, A BEITELMAN
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TECHNICAL REPORT M-286
January 1981

LEVEL II

CORROSION CONTROL OF PILINGS IN SEAWATER: BUZZARDS BAY

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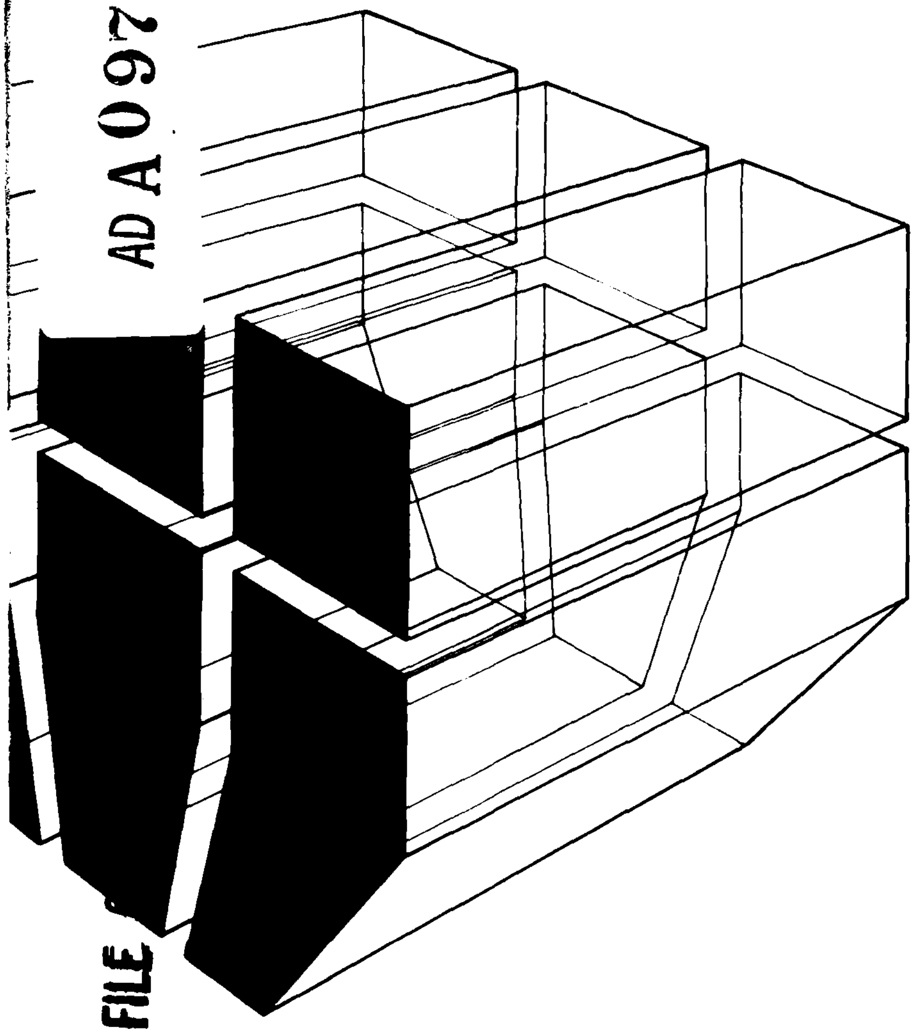

by
A. Kumar
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This report assesses (1) the rate of corrosion of steel piles with and without cathodic protection after 5 years in seawater at Buzzards Bay, MA, and (2) the performance of the piles' coatings.

One row of pilings was pulled out and inspected. The U.S. Army Construction Engineering Research Laboratory then established performance ratings for the following coatings: organic, organic over metal filled, organic over metal filled with cathodic protection, metallic, and organic over metallic.

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It is concluded that (1) sacrificial anodes of zinc and aluminum effectively reduced the corrosion rate of bare carbon steel (ASTM A 36) piles in the immersed zone from 3.4 mils/yr to zero, and (2) the coating performing best was coal tar epoxy over zinc-rich primer.

FOREWORD

This investigation was conducted for the Directorate of Civil Works, Office of the Chief of Engineers (OCE) under CWIS 31204 "Corrosion Mitigation in Civil Works Projects." Mr. J. Robertson was the OCE Technical Monitor.

The work was performed by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. Quattrone is Chief of EM.

Appreciation is extended to CERL personnel who participated in the inspections: Mr. C. Hahin, Mr. F. Kisters, Mr. J. Aleszka, Ms. R. Hannan, Mr. W. Gordon, Mr. F. Kearney, Dr. R. Quattrone, and Mr. A. Beitelman.

COL L. J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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CORROSION CONTROL OF PILINGS IN SEAWATER: BUZZARDS BAY

1 INTRODUCTION

Background

In coastal areas, the Directorate of Civil Works, Office of the Chief of Engineers, has jurisdiction over many structures supported on pilings--harbors, bridges, and buildings, for example. The design life of these structures can range from a few years to 100 years. Steel pipe and H-pilings have generally been used for foundations in coastal areas; recently, prestressed concrete pilings also have been used widely.

Several types of protective coatings are available for steel pilings. In brackish water or saltwater aplications, where the life of even the best available coatings can be somewhat limited, cathodic protection is used as supplemental protection.[1] In addition, the chemical industry continually develops new coatings, some of which, though expensive, may be used in seawater. Zinc-rich primers also can improve the performance of coating systems.

For rapid screening of these newly developed coatings and primers, nondestructive measurement techniques capable of predicting long-life (50-year) performance based on tests of shorter duration are extremely valuable. However, such tests performed in the laboratory, though indicative of coating performance, do not simulate actual field exposures. Field tests at various geographic locations are necessary because the effects of conditions such as marine biofouling are important parameters which cannot be simulated easily in the laboratory.

In response to this problem, the U.S. Army Corps of Engineers and the National Bureau of Standards (NBS) began a field study of piling corrosion in 1967, when 31 sets of piles (three identical piles per set) were installed near Dam Neck, VA. Every 5 years, one row of pilings was to be extracted and examined for corrosion damage.

To determine the effect of geography and temperature, the Coastal Engineering Research Center (CERC) selected two more sites (La Costa Island, FL, and Buzzards Bay, MA). The installation of 31 sets of piles (three per set) at La Costa Island was completed in January 1971, and annual inspections have been conducted since then. The results of the 5-year inspection have been previously published.[2] CERC evaluated the pilings through June 1974, when the inspection responsibility was transferred to the U.S. Army Construction Engineering Research Laboratory (CERL). The Dam Neck and La Costa Island studies are to be completed in FY81.

CERL was responsible for installing pilings at Buzzards Bay in October 1974, and conducted the first inspection in July 1975.[3] Annual inspections of the piles in place have been conducted since then.[4] The first set of pilings was extracted in 1979, as this report explains; the Buzzards Bay phase of the study will be completed in 1989.

When the Dam Neck, La Costa Island, and Buzzards Bay studies are finished, the data from all three sites will be analyzed to draw conclusions and develop recommendations about pile coatings.

Objective

The objective of this report is to assess (1) the rate of corrosion of steel with and without cathodic protection, and (2) the performance of coatings after 5 years in seawater at Buzzards Bay, MA.

Approach

Twenty-four sets (three pilings per set) of American Society for Testing and Materials (ASTM) A 36 or 690 steel H-pilings were exposed at Buzzards Bay, MA. Most of the pilings were coated or had cathodic protection. One row of pilings was pulled out and inspected visually. (The piles had been inspected by electrochemical measurements from 1975 to 1979.) CERL then established performance ratings for the following coatings: organic, organic over metal filled, organic over metal filled with cathodic protection, metallic, and organic over metallic.

---

[1] A. Kumar and D. Wittmer, "Coatings and Cathodic Protection of Pilings in Seawater: Results of 5-Year Exposure," *Materials Performance*, Vol 18, No. 12 (1979), p 9-19.

[2] Kumar and Wittmer, *Materials Performance*, p 9-19.

[3] A. Kumar and C. Hahin, *First Annual Inspection of Buzzards Bay Pilings*, Technical Report M-172/ADA024381 (U.S. Army Construction Engineering Research Laboratory [CERL], 1976).

[4] E. Kearney, *Corrosion of Steel Pilings in Seawater Buzzards Bay 1975-1978*, Interim Report M-275/ADA078626 (CERL, November 1979).

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Mode of Technology Transfer

The information in this study will be incorporated into Corps of Engineers Guide Specification CW-09940, *Painting: Hydraulic Structures and Appurtenant Works*, and Technical Manual (TM) 5-811-4, *Electrical Design: Corrosion Control*.

2 BUZZARDS BAY FIELD STUDY

Test Site and Protective Coating Systems

Figure 1 shows the location of the Buzzards Bay test site; the arrangement of the pilings is shown in Figure 2. CERL jetted into place 24 steel piles in three rows designated A, B, and C parallel to the shoreline (Figures 3 and 4). The piles are made of either ASTM A 36 or ASTM 690 (Mariner steel) (Table 1). The steel H-piles are 8 in. × 8 in. × 40 ft (20.32 cm × 20.32 cm × 12.19 m) and weigh 36 lb/ft (54 kg/m). Eight prestressed concrete pilings were also installed farther from the Stoney Point Dike.

Some piles have no coating or sacrificial anodes, while others have both coatings and cathodic protection. Some of the protective coating systems at the Buzzards Bay test site are the same as those at the Dam Neck and La Costa Island sites. The systems include organic coatings, metallic coatings, and zinc-rich primers with top coats. The organic coatings are coal tar epoxies, saran, vinyl, phenolic mastic, epoxy polyamide, epoxy over inorganic ceramic, and polyester over glass flake. Metallic coatings include flame-sprayed aluminum and zinc with and without organic seal coats. (See Table 1 for a complete list of coatings and their sources.) The coatings were applied after the base metal was sand blasted to "near white metal," according to Steel Structures Painting Council (SSPC) Specification SSPC-SP-10-63T. Row A piles are completely coated, row C piles are coated except for the lower 15 ft (4.57 m). Row B piles are coated except in areas called windows, as shown in Figures 4 and 5. The piles are identified by raised weld bead numbers near the top. Row B is nearest the beach; row E, which contains the concrete pilings, is farthest from the beach (Figure 4). Stainless steel rods are welded between the inside flanges of each pile so that electrical contact can be made for electrochemical measurements.

Zinc or aluminum sacrificial anodes for the cathodically protected piles were mounted near the sand zone. The zinc anodes are 4 × 4 × 36 in. (10.1 × 10.1 × 91.4 cm) and weigh about 150 lb (68.0 kg) when new; the aluminum nodes are 4 × 4 × 38 in. (10.1 × 10.1 × 96.7 cm) and weigh 60 lb (27.2 kg) when new. Two such anodes were installed on each pile to be cathodically protected. (The details of the anode mountings are shown in Figure 6.)

Annual Inspections

After placement, the pilings had five annual inspections consisting of visual observations and electrochemical measurements. Each 40-ft (12.19-m) length of piling can be divided into three zones: the embedded zone (21 to 40 ft, or 6.40 to 12.15 m), immersion zone (16 to 21 ft, or 4.88 to 6.40 m), and atmospheric zone (0 to 12 ft, or 0 to 3.66 m). The pilings were visually inspected only in the atmospheric zone, which was not under water. The upper 5 to 6 ft (1.52 to 1.83 m) of the piles were coated with cormorant guano, which was not thick enough to obscure observations. The splash zone (7 to 12 ft, or 2.13 to 3.66 m) was covered with marine biofouling, such as barnacles.

Three types of electrical measurements were taken: pile corrosion potential measurements, cathodic protection index (CPI) measurements, and polarization measurements. Electrical contact with the stainless steel rods in the piles was made with vise clamps connected to the cable wires. The protection offered by sacrificial anodes was assessed with pile potential measurements. Miller Model M-3-M Multimeter, or a digital voltmeter, was used to measure the potential with respect to a copper-copper sulphate electrode immersed in seawater.

CERL determined CPIs for all coated piles (except those with sacrificial anodes) by forming a galvanic couple between them and a bare pile, and then measuring the potential with zero applied current. The current was then increased to lower the initial potential to −0.85 V for the coated piles. The current was constantly adjusted to keep the lowered value of the potential constant during a 3-minute run. The initial and final values of the current and potential were then used to calculate the CPI value with Eq 1:

$$CPI = \Delta V/\Delta I \qquad [Eq\ 1]$$

where ΔV = change in voltage

ΔI = current required to shift the voltage.

The corrosion rate measurements were conducted by Schwerdtfeger and McDorman's "polarization break" method, which uses breaks in the anodic and

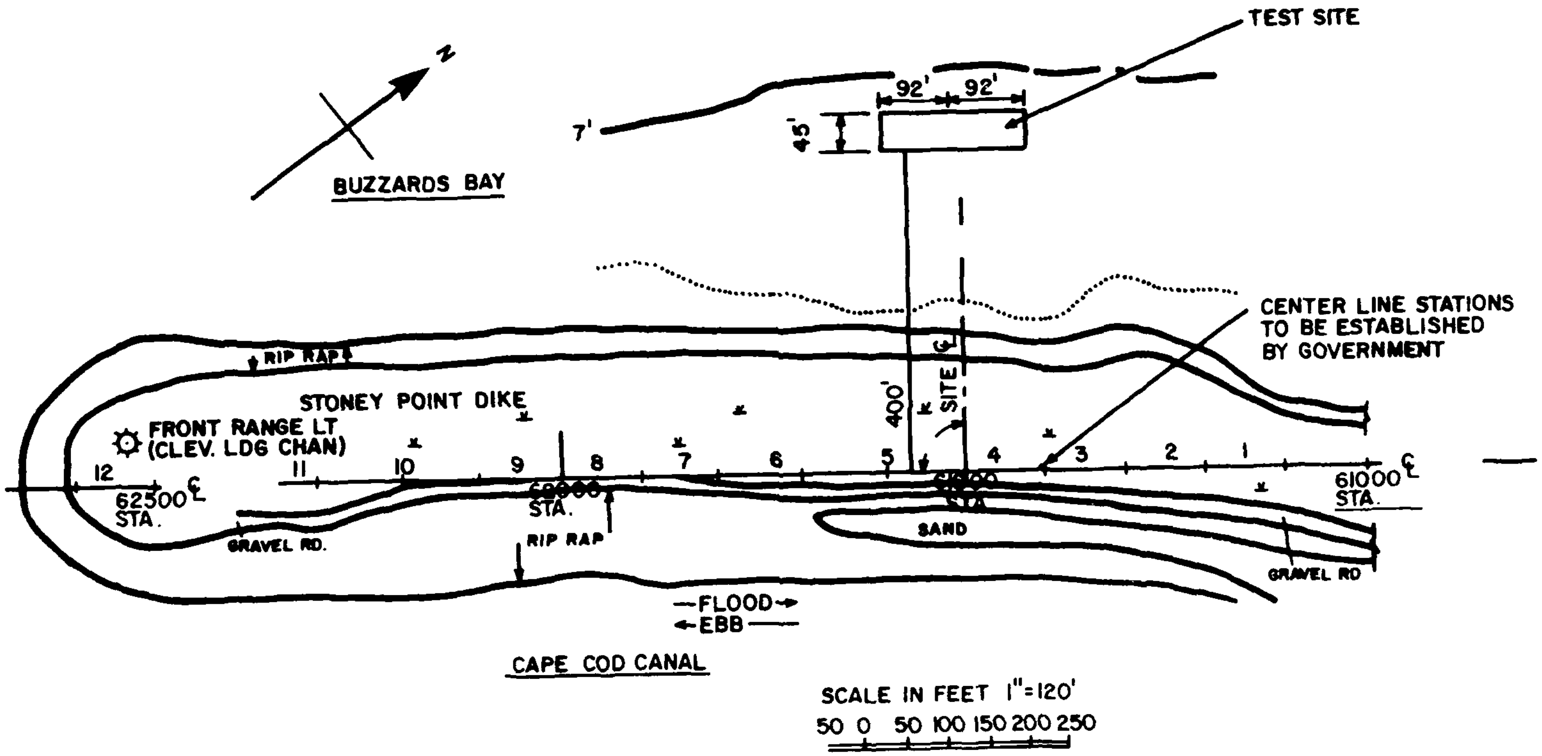
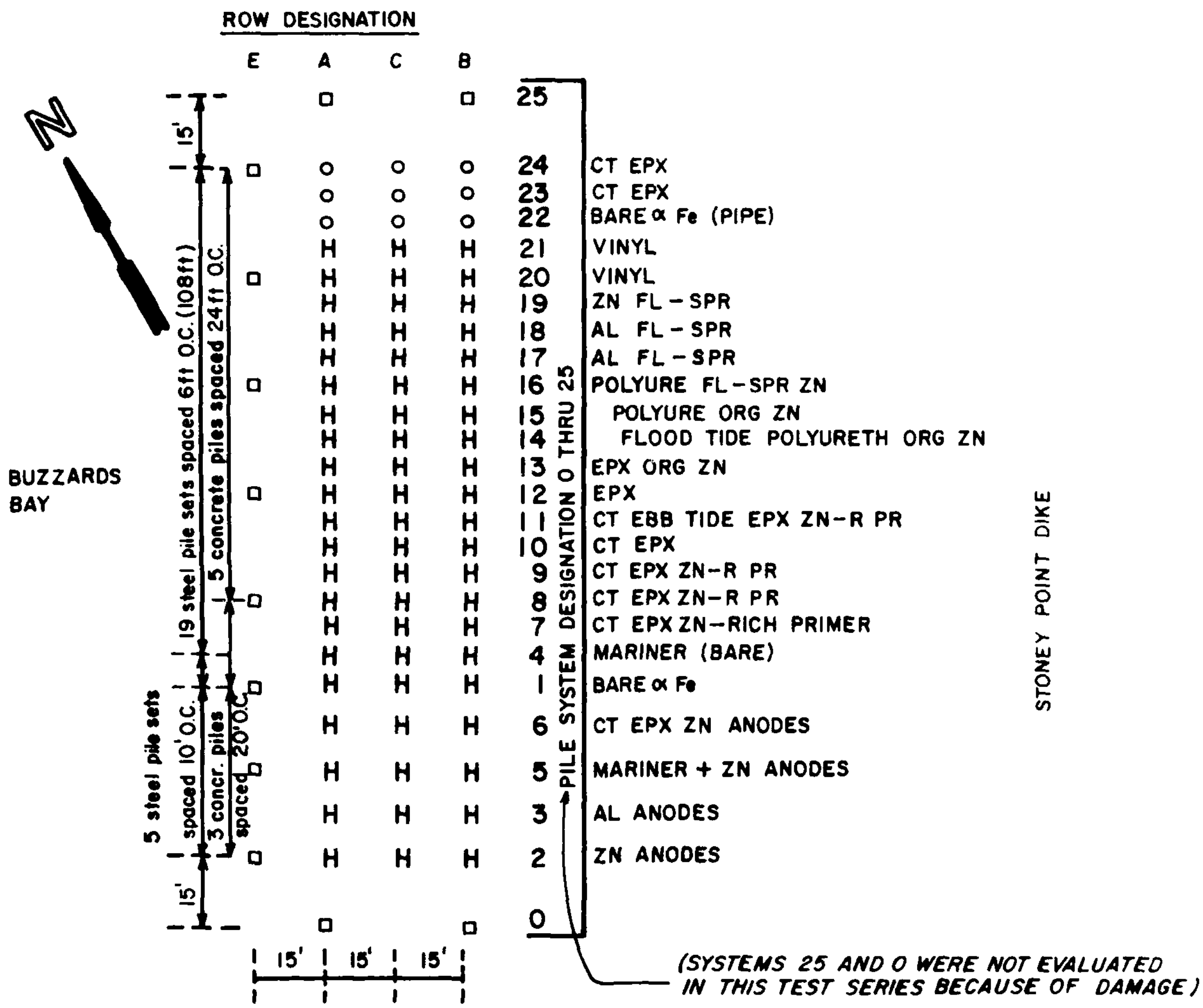


Figure 1. Buzzards Bay test site. (Metric conversion factor: 1 ft = 0.3048 m.)



SYMBOLS: H DENOTES HP 8" x 8" x 36LB. STEEL PILES

O DENOTES 8" DIA. SCH. 40 STEEL PIPE PILES

□ DENOTES 12" SQ. PRESTRESSED CONCRETE PILE (CONTRACTOR FURNISHED)

CT DENOTES COAL TAR

EPX DENOTES EPOXY

Figure 2. Installation plan. (Metric conversion factors: 1 ft = 0.3048 m; 1 in = 2.54 cm; 1 lb = 0.4536 kg.)

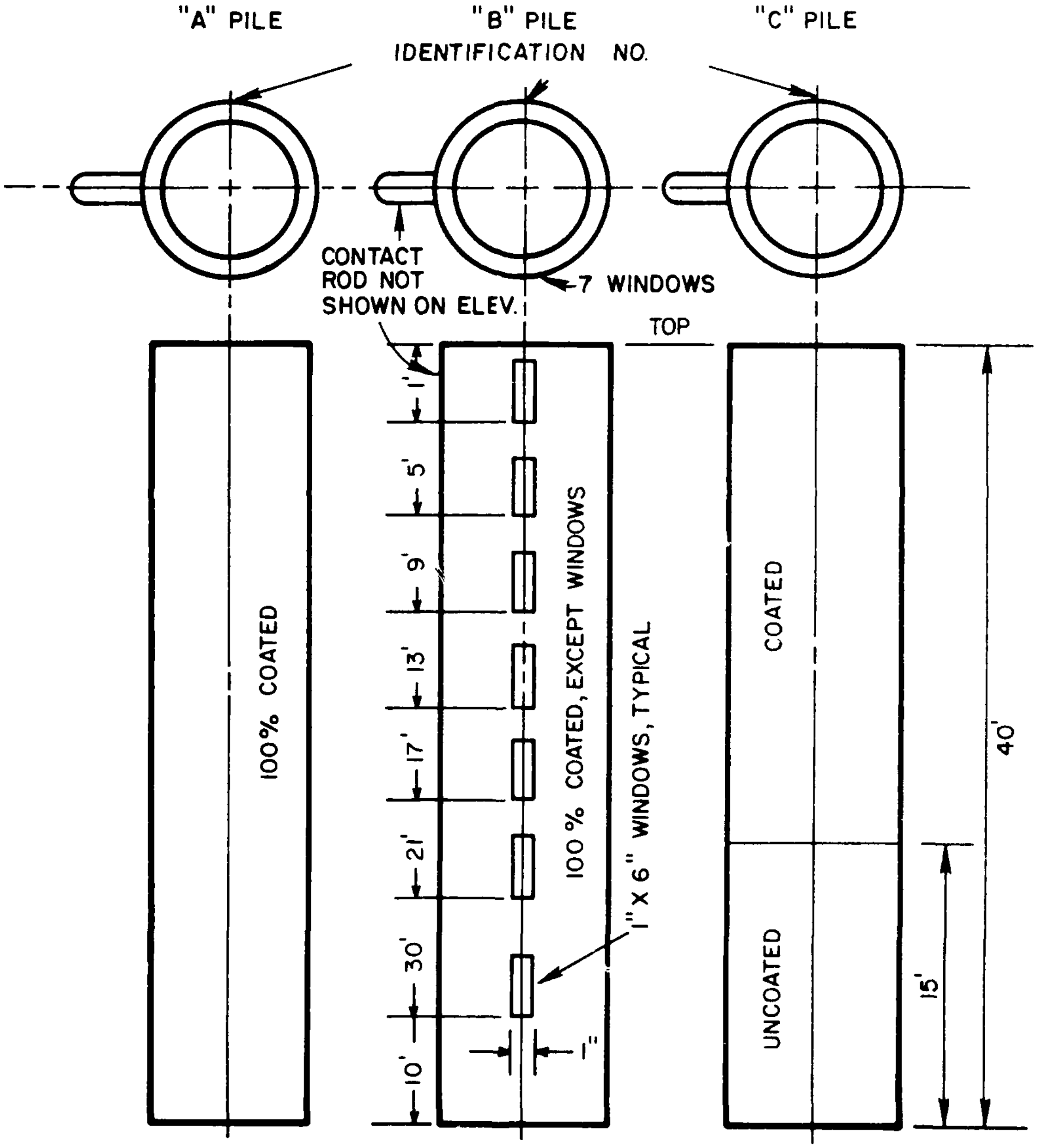


Figure 3. Pipe pile coating detail. (Metric conversion factors: 1 ft = 0.3048 m; 1 in. = 2.54 cm.)

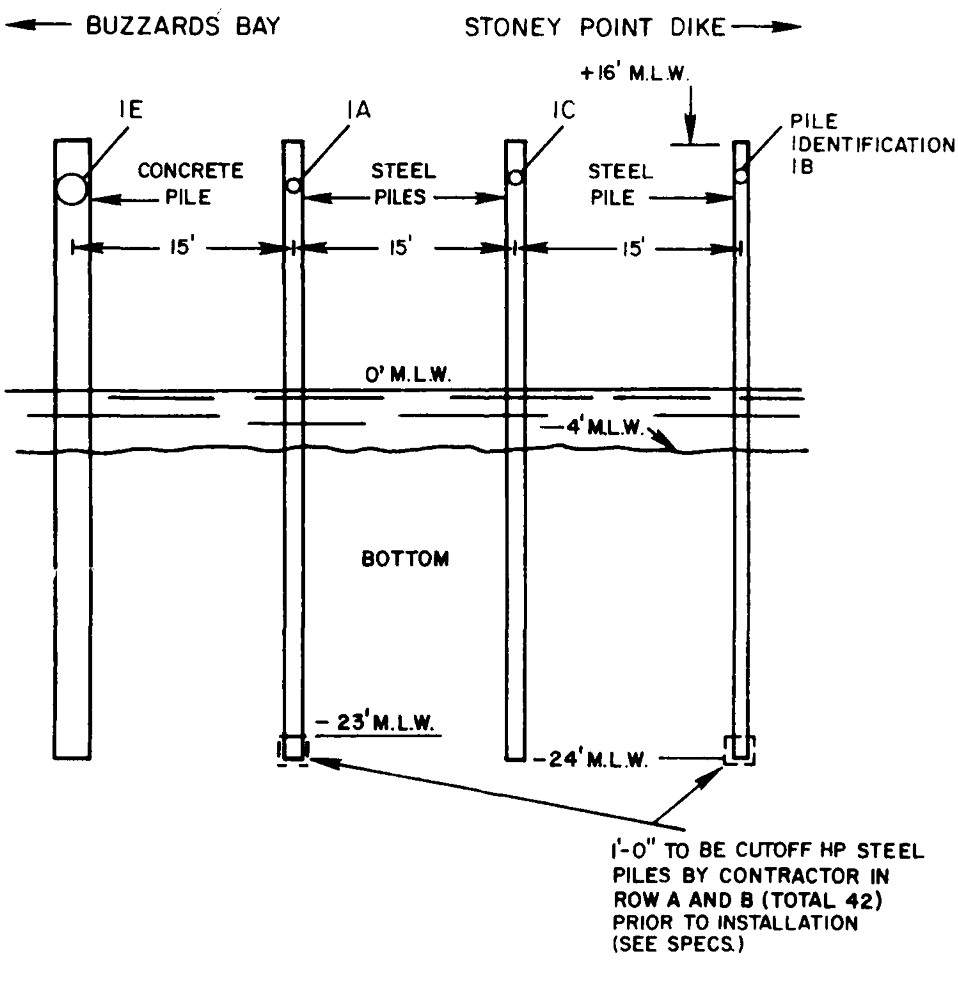


Figure 4. Pile system at Buzzards Bay. (Metric conversion factors: 1 ft = 0.3048 m, 1 in. = 2.54 cm.)

Table 1

Test Pile Preparation Details

System No.	Type of Pile*	Type Pile and Protection	No. of Coats	Total Dry Coating Thickness (mils)**	Coating Source[+]	Remarks
1	H	Bare Carbon Steel	------	---------	-------------	--------
2	H	Bare Carbon Steel with Zinc Anodes	------	---------	-------------	2 Anodes
3	H	Bare Carbon Steel with Aluminum Anodes	------	---------	-------------	2 Anodes
4	H	Bare Mariner Steel	------	---------	-------------	--------
5	H	Bare Mariner Steel with Zinc Anodes	------	---------	-------------	2 Anodes
6	H	Coal Tar Epoxy, over Zinc-Rich Primer, with Zinc Anodes	------	---------	-------------	2 Anodes
		- Epoxy Zinc-Rich Primer CERL Formula No. E-303	1	2.5 (0.06 mm)	Iowa Paint Mfg. Co. (Via CERL Paint Lab)	
		- Formula C-200, Coal Tar Epoxy	2	16–20 (0.41–0.51 mm)	Koppers	Koppers
7	H	Coal Tar Epoxy, over Zinc-Rich Primer				
		- Epoxy Zinc-Rich Primer CERL Formula No. E-303	1	2.5 (0.06 mm)	Iowa Paint Mfg. Co. (Via CERL Paint Lab)	
		- Formula C-200, Coal Tar Epoxy	2	16–20 (0.41–0.51 mm)	Koppers	
8	H	Coal Tar Epoxy, over Zinc-Rich Primer				
		- Porter Zinc-Lok No. 352 Primer	1	1 (0.03 mm)	Porter Paint Co.	
		- Formula C-200, Coal Tar Epoxy	2	16–20 (0.41–0.51 mm)	Koppers	
9	H	Coal Tar Epoxy, over Zinc-Rich Primer, Aluminum Oxide Armored at Mud Line				
		- Epoxy Zinc-Rich Primer NCR Formula No. E-303	1	2.5 (0.06 mm)	Iowa Paint Mfg. Co. (Via CERL Paint Lab)	4th coat + grit to be applied 17 ft and 23 ft (5.18 and 7.01 m) and bottom of pile
		- Formula C-200, Coal Tar Epoxy	2	16–20 (0.41–0.51 mm)	Koppers	
		- Formula C-200, Coal Tar Epoxy + Aluminum Oxide Grit (No. 30) Broadcast into Wet Final Coat				

*Steel H-piles are 40 ft (12.19 m) lengths of 8 in. × 8 in. × 36 lb (20.32 cm × 20.32 cm × 16.33 kg) mild carbon steel, except systems 4, 5, and 11, which are "Mariner" steel H-piles. Systems 22, 23 and 24 are pipe piles, mild carbon steel, 8 in. (20.32 cm) diameter, schedule 40, 0.322 in. (0.82 cm) wall thickness.

**Film thickness tolerance per coat may be plus or minus 15 percent of given thickness per coat when no thickness range is given.

[+] An approximately equal brand name coating with application and preparation instructions can be furnished by the Government from the same or another source. CERL is symbol for the Paint Laboratory at the U.S. Army Construction Engineering Research Laboratory.

Table 1 (cont'd)

System No.	Type of Pile*	Type Pile and Protection	No. of Coats	Total Dry Coating Thickness (mils)**	Coating Source†	Remarks
10	H	Coal Tar Epoxy, over Epoxy Resin Primer				
		- Epoxy Resin Primer	1	3 (0.08 mm)	Porter Paint Co.	
		- Formula C-200, Coal Tar Epoxy	2	16–20 (0.41–0.51 mm)	Koppers	
11	H	Coal Tar Epoxy, over Zinc-Rich Primer, on Mariner Steel				Mariner steel pile
		- Epoxy Zinc-Rich Primer NCR Formula No. E-303	1	2.5 (0.06 mm)	Iowa Paint Mfg. Co. (Via CERL Paint Lab)	
		- Formula C-200, Coal Tar Epoxy	2	16–20 (0.41–0.51 mm)	Koppers	
12	H	Epoxy over Inorganic Ceramic				
		- Plas-Chem Zinc-ite Primer	1	3–4 (0.08–0.09 mm)	Plas Chem Corp.	
		- Plas-Chem Ceram-ite No. 101	1	5–6 (0.12–0.15 mm)		
		- Plas-Chem 2140Z High Build Epoxy	1	7–8 (0.18–0.20 mm)	Plas Chem Corp.	
13	H	Epoxy over Organic Zinc Primer				
		- Zincor No. 11 Primer	1	1–1.5 (0.03–.04 mm)	Plas Chem Corp.	
		- Chem-Pon 2310X Red	1	8–9 (0.20–0.23 mm)	Plas Chem Corp.	
		- Chem-Pon 2310X Gray	1	8–9 (0.20–0.23 mm)	Plas Chem Corp.	
14	H	Polyurethane over Organic Zinc-Rich				
		-Chemglaze Zinc-Rich Primer 9927	1	3 (0.08 mm)	Hughson Chem	
		-Chemglaze II	2	3–5 (0.08–0.12 mm)	Hughson Chem	
15	H	Polyurethane over Organic Zinc-Rich with an Intermediate Elastomer Coat				
		-Chemglaze Zinc-Rich Primer 9927	1	3 (0.08 mm)	Hughson Chem	
		- M312 Elastomer	1	6–8 (0.15–0.20 mm)	Hughson Chem	M312 is High Build - 1 coat up to 10 mils (0.25 mm)
		-Chemglaze II	2	3–5 (0.08–0.12 mm)	Hughson Chem	

*Steel H-piles are 40 ft (12.19 m) lengths of 8 in. × 8 in. × 36 lb (20.32 cm × 20.32 cm × 16.33 kg) mild carbon steel, except systems 4, 5, and 11, which are "Mariner" steel H-piles. Systems 22, 23 and 24 are pipe piles, mild carbon steel, 8 in (20.32 cm) diameter, schedule 40, 0.322 in. (0.82 cm) wall thickness.

**Film thickness tolerance per coat may be plus or minus 15 percent of given thickness per coat when no thickness range is given.

†An approximately equal brand name coating with application and preparation instructions can be furnished by the Government from the same or another source. CERL is symbol for the Paint Laboratory at the U.S. Army Construction Engineering Research Laboratory.

Table 1 (cont'd)

System No.	Type of Pile*	Type Pile and Protection	No. of Coats	Total Dry Coating Thickness (mils)**	Coating Source+	Remarks
16	H	Polyurethane over Flame-Sprayed Zinc, with Intermediate Wash-coat Primer				
		- Flame-Sprayed Zinc	1	3–4 (0.08–0.09 mm)	Metalweld or Metco Urecal Co.	
		- Washcoat Primer Formula 117, MIL-P-15328	1	0.5 (0.12 mm)	Via Seaguard Co.	
		- Urecal 9301 Polyurethane	2	4 (0.09 mm)		
17	H	Aluminum, Flame Sprayed (Wire)	1	6 (0.15 mm)	Metalweld, Metco or equal	Steel Wire Flash Bonding Coat, 1 mil (0.03 mm)
18	H	Aluminum, Flame Sprayed with Wash-coat Primer and Aluminum Vinyl Sealer				Steel Wire
		- Flame-Sprayed Aluminum (Wire)	1	3–4 (0.08–0.09 mm)	Metalweld, Metco or equal Via Sea-quard Co.	
		- Washcoat Primer Formula 117, MIL-P-15328	1	0.5 (0.12 mm)		
		- Metcoseal AV, Aluminum Vinyl Sealer	2	2 (0.05 mm)	Metco	
19	H	Zinc, Flame Sprayed, with Coal Tar Emulsion over Coal Tar Solution Top coats				
		- Flame-Sprayed Zinc (Wire)	1	3–4 (0.08–0.09 mm)	Metalweld or Metco	
		- Wise Chem T-265 Coal Tar Solution	1	15 (0.38 mm)	Wise Chem Co.	
		- Wise Chem T-264 Coal Tar Emulsion	1	7–8 (0.18–0.20 mm)	Wise Chem Co.	
20	H	Vinyl Glass Flake over Vinyl Zinc-Rich				
		- Vinyl Zinc Rich	1	2–3 (0.05–0.08 mm)	CERL Paint Lab	
		- Vinyl Glass Flake	3	6 (0.15 mm)	CERL Paint Lab	
21	H	Vinyl Mastic over Synthetic Resin Tiecoat over Washcoat Inorganic Zinc Primer				Curing Solution to be removed by freshwater
		- Dimetcote No. 3 + D3 Curing Solution	1	3 (0.08 mm)	Amercoat Corp.	
		- No. 54 Tiecoat	1	1 (0.03 mm)	Amercoat Corp.	
		- Vinyl Mastic No. 87	1	10 (0.25 mm)	Amercoat Corp.	

*Steel H-piles are 40 ft (12.19 m) lengths of 8 in × 8 in. × 36 lb (20.32 cm × 20.32 cm × 16.33 kg) mild carbon steel, except systems 4, 5, and 11, which are "Mariner" steel H-piles. Systems 22, 23 and 24 are pipe piles, mild carbon steel, 8 in. (20.32 cm) diameter, schedule 40, 0.322 in. (0.82 cm) wall thickness.

**Film thickness tolerance per coat may be plus or minus 15 percent of given thickness per coat when no thickness range is given.

+An approximately equal brand name coating with application and preparation instructions can be furnished by the Government from the same or another source. CERL is symbol for the Paint Laboratory at the U.S. Army Construction Engineering Research Laboratory.

Table 1 (cont'd)

System No.	Type of Pile*	Type Pile and Protection	No. of Coats	Total Dry Coating Thickness (mils)**	Coating Source[†]	Remarks
22	Pipe	Bare Carbon Steel	----	--------	----------	-----
23	Pipe	Coal Tar Epoxy over Zinc-Rich Primer				
		- Epoxy Zinc-Rich Primer NCR Formula No. E-303	1	2.5 (0.06 mm)	Iowa Paint Mfg. Co. (Via CERL Paint Lab)	
		- Formula C-200, Coal Tar Epoxy	2	16–20 (0.41–0.51 mm)	Koppers	
24	Pipe	Coal Tar Epoxy, Armored at Mud Line over Zinc-Rich Primer				
		- Epoxy Zinc-Rich Primer NCR Formula No. E-303	1	2.5 (0.06 mm)	Iowa Paint Mfg. Co. (Via CERL Paint Lab)	4th coat & Al oxide to be applied between 17 and 23 ft (5.18 and 7.01 mm) from bottom of pile
		- Formula C-200, Coal Tar Epoxy	2	16–20 (0.41–0.51 mm)	Koppers	
		- Formula C-200, + Aluminum Oxide (No. 30 Grit) Broadcast into Wet Final Coat	1	10 (0.25)	Koppers	

*Steel H-piles are 40 ft (12.19 m) lengths of 8 in. × 8 in. × 36 lb (20.32 cm × 20.32 cm × 16.33 kg) mild carbon steel, except systems 4, 5, and 11, which are "Mariner" steel H-piles. Systems 22, 23 and 24 are pipe piles, mild carbon steel, 8 in. (20.32 cm) diameter, schedule 40, 0.322 in. (0.82 cm) wall thickness.

**Film thickness tolerance per coat may be plus or minus 15 percent of given thickness per coat when no thickness range is given.

[†] An approximately equal brand name coating with application and preparation instructions can be furnished by the Government from the same or another source. CERL is symbol for the Paint Laboratory at the U.S. Army Construction Engineering Research Laboratory.

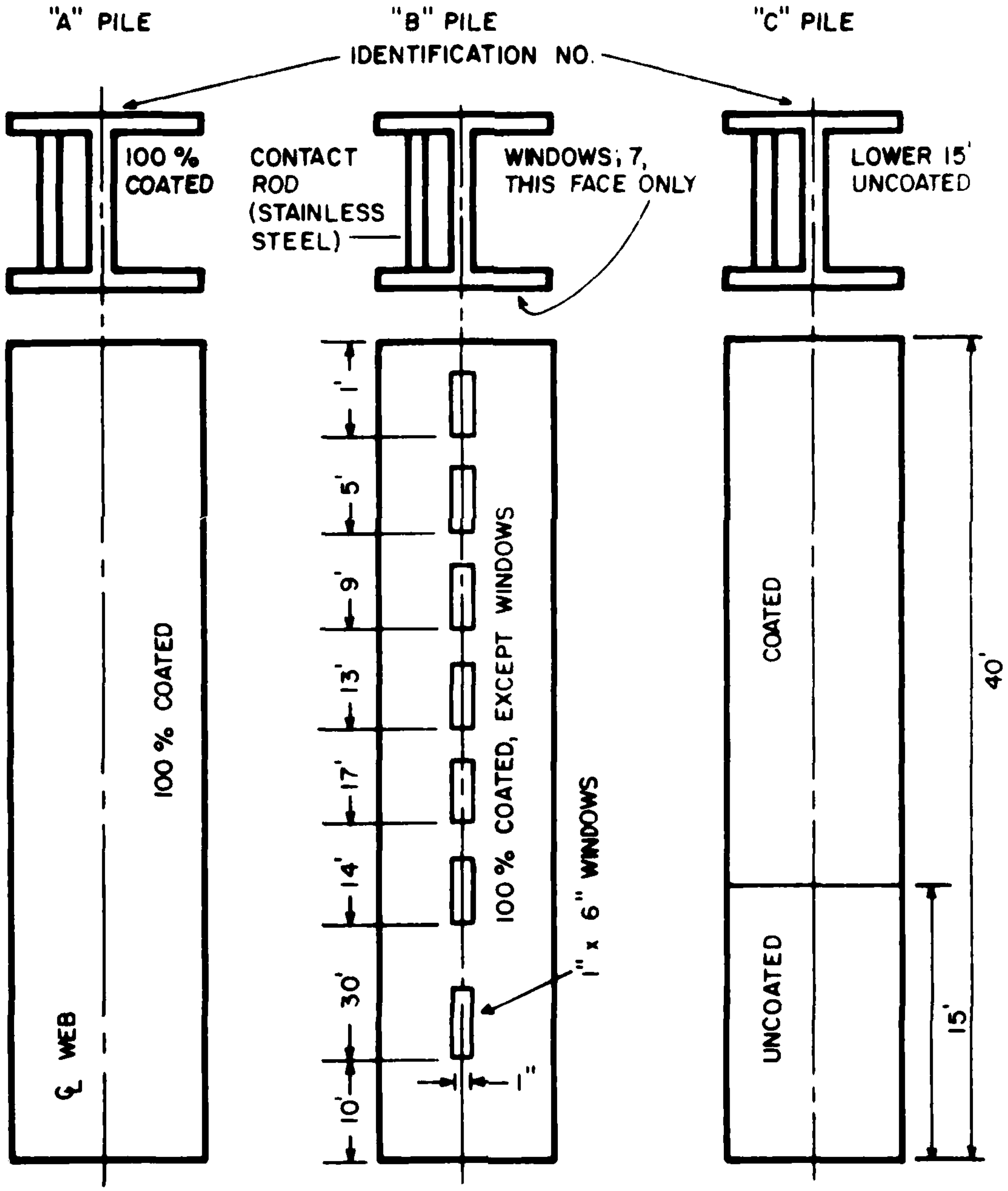


Figure 5. H-pile coating detail. (Metric conversion factors: 1 ft = 0.3048 m, 1 in. = 2.54 cm.)

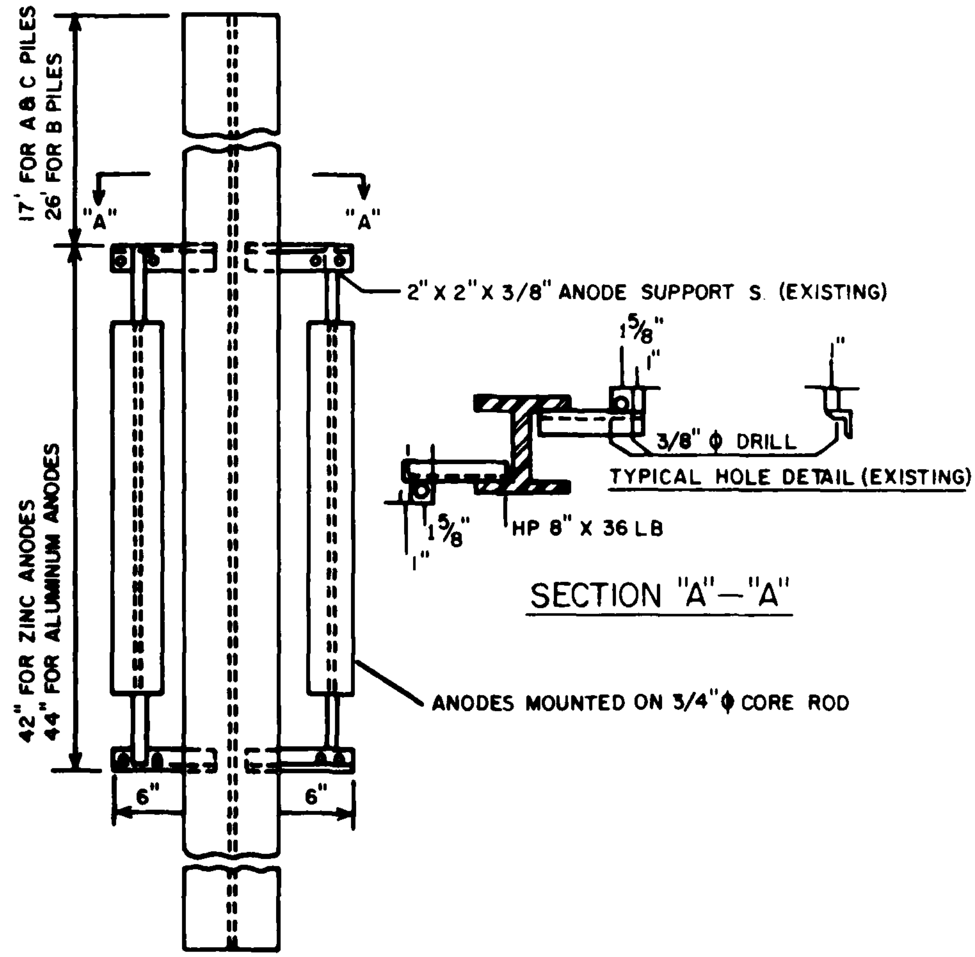
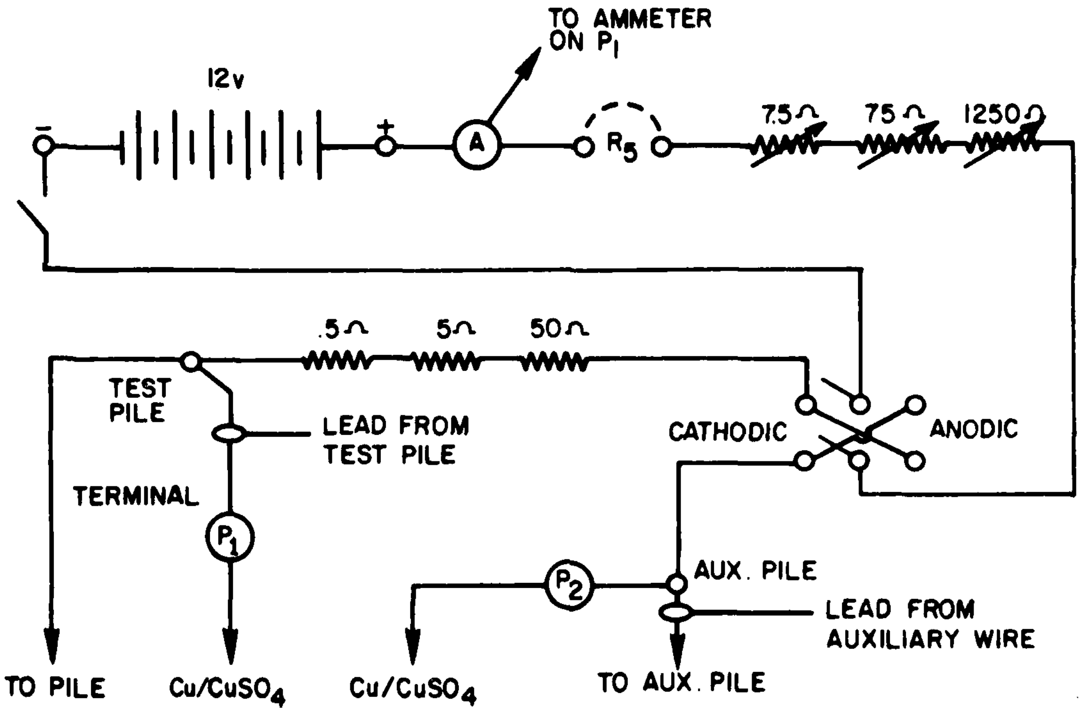


Figure 6. Anode mounting detail. (Metric conversion factors: 1 ft = 0.3048 m; 1 in. = 2.54 cm.)



P_1 = MILLER M-3 PM/VM OR HIGH RESISTANCE VM; USED FOR MONITORING POTENTIAL / VOLTAGE OF TEST PILES.

P_2 = MILLER M-3; FOR AUXILIARY PILE VOLTAGE

Figure 7. Circuit diagram for measurement of cathodic protection index.

cathodic polarization curves to identify the corrosion rate by a calculated corrosion current, I_c.[5] I_c can be calculated from the following relationship, which was derived by Pearson and confirmed by Holler.[6]

$$I_c = (I_p)(I_q)/(I_p + I_q) \qquad \text{[Eq 2]}$$

where I_p and I_q = the tangent intersection of the portions of the anodic and cathodic curves, respectively. These polarization curves are obtained by increasing the current from zero over equal periods of time e.g., at 5-minute intervals.

Figure 7 illustrates the circuit diagram used in making the polarization and CPI measurements

[5] W. J. Schwerdtfeger and O. N. McDorman, "Measurement of Corrosion Rate of Metal From Its Polarizing Characteristics," *Journal of the Electrochemical Society*, Vol 99 (1952), p 407.

[6] J. M. Pearson, "'Null' Methods Applied to Corrosion Measurements," *Transactions of the Electrochemical Society*, Vol 81 (1942), p 485, H. D. Holler, "Studies on Galvanic Couples," *Journal of the Electrochemical Society*, Vol 97 (1950), p 277.

Five-Year Inspection

In November 1979, the row C pilings were removed by hooking a crane to the pull-holes on the pilings. Water jetting was used to loosen the bottom material around the piles to prevent piling damage. After removal, the piles were sent by barge to North Haven, CT, where they were loaded onto wood supports

Wood separators on the supports protected the coatings from being damaged by contact with a hard surface. The piles were spaced to allow room to turn the piles for inspection of all surfaces. Then the piles were cleaned; but since they were covered by guano in the atmospheric zone, fouled by marine organisms in the immersed zone, and coated with attached oyster shells and sand in the embedded zone, more than a conventional water wash was needed. Hand-scraping removed most marine fouling without damage to the coatings. After this cleaning, coating thicknesses for the immersed zone were measured with an Elcometer dry-film-thickness gage. The piling next had to be steam cleaned to remove the guano. Charts were constructed displaying the corrosion behavior of the pilings (see the appendix), and the coated piles were rated in accordance with ASTM D 610-68 (Table 2).

The bare steel piles had to be sandblasted before their flange thicknesses could be measured. After the sandblasting operation, the flange thickness was measured along the length of each of the bare piles, and a profile was made.

3 RESULTS AND DISCUSSION

Electrochemical Measurements

Potential Measurements

The potentials of the protected piles (Table 3) were measured with respect to a copper-copper sulphate half-cell. The results of the inspections from 1975 to 1979 show that no significant changes in potentials occurred, indicating that the sacrificial anodes provide protection in the immersed zone.

CPI Measurements

The CPI indicates the current required to cathodically protect a pile's bare area in the immersed zone. The index reflects the amount of current required to shift the potential of the pile in the cathodic direction to attain -0.85 V with respect to a copper-copper sulphate electrode.

Recent laboratory investigations of vinyl and coal tar epoxy coatings and bare steel immersed in tap and salt water at CERL have demonstrated the direct correlation between change in current and change in bare steel area.[7] Since the CPI is inversely proportional to the change in current (Eq 1), a direct correlation exists between CPI and bare steel exposed to an aqueous medium. A decrease in the CPI means that a larger area of bare steel is exposed to water (larger change in current required) and thus indicates coating deterioration.

The 5 years of data from La Costa Island has shown that CPI versus time of exposure plots as a straight line on log-log coordinates;[8] so the CPI follows a relation of the type:

$$CPI = K_t^m + C_o \qquad \text{[Eq 3]}$$

K = ordinate intercept at log t = 1

C_o = constant at t (initial CPI at immersion)

t = time of exposure.

Plotting the CPIs versus time durations on log-log plots at La Costa permitted prediction of the deterioration of the coatings, as demonstrated by a negative slope. However, some coatings, such as flame-sprayed metallics, had a completely flat slope or a slightly positive one, indicating formation of protective corrosion products, such as aluminum oxide or zinc oxide, in the porous flame-sprayed metal. All other systems showed negative logarithmic behavior, with decay of index m (Eq 3) depending on the coating and mil thickness. The results of CPI measurements at Buzzards Bay are shown in Table 4.

During 1977 and 1978, an error was made in the electrical measurement of CPI and polarization current.[9] The current-carrying wire was also used as the potential measuring wire. This caused the actual potential shift at the test pile to be less than the measured potential shift by the IR drop in the wire.

For example, the actual potential of the bare steel pile 1A was only -0.67 when the measured potential at the voltmeter was -1.30 V. The -0.63 V difference was caused by the IR drop -I being equal to 0.5 amps. For coated pile 13A, the measured potential was -1.15 V, but the actual potential was -0.90V for a current of 0.12 amps.

[7] A. Kumar and D. Wittmer, "Coatings and Cathodic Protection of Pilings in Seawater: Results of 5-Year Exposure," *Materials Performance*, Vol 18, No. 12 (1979), p 9-19.

[8] Kumar and Wittmer, *Materials Performance*, p 9-19; E. Escalante, et al., *Protection of Steel Piles in a Natural Seawater Environment Part II*, NBSIR 76-1104 (National Bureau of Standards, 1976).

[9] F. Kearney, *Corrosion of Steel Pilings in Seawater: Buzzards Bay 1975-1978*, Interim Report M-275/ADA078626 (CERL, November 1979).

Table 2

Scale and Description of Rust Grades*

Rust Grades**	Description	SSPC-ASTM Photographic Standard
10	No rusting or less than 0.01 percent of surface rusted	unnecessary
9	Minute rusting, less than 0.03 percent of surface rusted	No. 9
8***	Few isolated spots, less than 0.1 percent of surface rusted	No. 8
7	Less than 0.3 percent of surface rusted	none
6†	Extensive rust spots but less than 1 percent of surface rusted	No. 6
5	Rusting to the extent of 3 percent of surface rusted	none
4††	Rusting to the extent of 10 percent of surface rusted	No. 4
3†††	Approximately one-sixth of the surface rusted	none
2	Approximately one-third of the surface rusted	none
1	Approximately one-half of the surface rusted	none
0⁺	Approximately 100 percent of the surface rusted	unnecessary

Table 3

Potential Measurements: Pilings With Sacrificial Anode Cathodic Protection

Pile No.	Voltage 1975	Voltage 1976	Voltage 1977	Voltage 1978	Voltage 1979
2A	-1.05	-1.06	-1.08	-1.03	-1.02
B	-0.97	-1.00	-1.04	-0.97	-1.06
C	-1.05	-1.07	-1.08	-1.03	
3A	-1.04	-1.06	-1.08	-1.01	-1.09
B	-.095	-1.00	-1.03	-0.96	-1.05
C	-1.03	-1.06	-1.08	-1.01	
5A	-1.05	-1.06	-1.07	-1.02	-1.08
B	-0.96	-1.00	-1.04	-0.96	-1.06
C	-1.06	-1.06	-1.06	-0.99	
6A	-1.06	-1.09	-1.09	-1.03	-1.1
B	-1.09	-1.09	-1.10	-1.03	-1.11
C	-1.07	-1.09	-1.08	-1.03	

---

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**Similar to European Scale of Degree of Rusting for Anti-Corrosive Paints (1961) (black and white).

***Corresponds to SSPC Initial Surface Conditions E (0 to 0.1 percent) and BISRA (British Iron and Steel Research Association) 0.1 percent.

†Corresponds to SSPC Initial Surface Conditions F (0.1 to 1 percent) and BISRA 1.0 percent.

††Corresponds to SSPC Initial Surface Condition G (1 to 10 percent).

†††Rust grades below 4 are of no practical importance in grading performance of paints.

⁺Corresponds to SSPC Initial Surface Condition H (50 to 100 percent).

Table 4

Tabulation of CPI 1975 to 1979

Pile No.	1975	1976	1977	1978	1979
1A	0.0487	.0333	2.78	4.6	.0555
B	0.058	0.327	0.058	5.86	.053
C	Aux	Aux	0.89	Aux	Aux
4A	0.0472	0.34	0.87	4.55	
B	0.0667	0.34	0.058	4.69	.058
C	---	0.321	Aux	6.25	0.49
7A	7.65	14.29	11.00	10.38	4.125
B	6.21	4.52	6.11		3.06
C	0.19	0.449	1.47		.186
8A	7.19	14.29	7.50		
B	7.20	2.75	1.96	7.65	
C	0.18	0.435	1.62	4.44	.178
9A	6.13	14.29	7.69	6.88	3.175
B	7.50	6.38	1.69	7.13	2.86
C	0.18	0.459	1.75	5.0	.179
10A	6.0	12.09	3.85	8.92	3.825
B	16.16	6.1	3.57	6.5	3.05
C	0.19	0.438	1.58	4.38	---
11A	5.33	12.5	7.50	10.0	0.154
B	8.70	4.21	1.85	6.43	2.89
C	0.16	0.44	1.57	5.0	.161
12A	*	2.73	1.82	5.2	.603
B	*	1.25	0.213	5.2	.202
C	0.16	0.409	1.48	4.8	---
13A	5.68	14.29	4.14	7.37	.092
B	15.15	2.65	1.20	6.08	1.75
C	0.15	0.458	1.55	4.7	.164
14A	7.65	20.0	2.08	5.56	1.14
B	15.18	3.25	0.773	6.0	1.32
C	0.17	0.455	1.52	4.79	.175
15A	7.22	11.04	17.86	20.0	8.25
B	13.71	2.73	1.53	6.52	1.97
C	0.71	0.44	1.49	4.64	.176
16A	*	*	2.34	*	---
B	*	*	0.556	*	---
C	0.16	*	1.18	4.5	.140
17A	*	0.669	1.65	*	.506
B	*	*	0.30	*	---
C	0.15	0.397	1.47	3.04	.132
18A	1.61	*	1.92	*	.916
B	*	1.11	1.19	*	2.22
C	0.16	0.484	1.47	4.35	.146
19A	*	*	1.79	*	
B	*	*	0.375	*	
C	*	*	1.43	5.88	1.13
20A	6.36	4.64	9.33	5.2	1.49
B	7.39	2.91	2.0	4.17	---
C	0.23	0.542	1.6	2.89	Bent by ice
21A	1.47	2.05	2.06	3.57	Bent by ice
B	6.25	2.65	0.619	3.41	Bent by ice
C	0.28	0.545	1.52	3.16	Bent by ice
22A	---	0.378	1.40	3.19	Bent by ice
B	---	0.375	0.076	2.95	Bent by ice
C	Aux	Aux	1.49	Aux Connection Broken	Bent by ice

*Initial Potential Reading -0.85 V (Potential was not shifted by 150 mV).

Table 4 (cont'd)

Pile No.	1975	1976	1977	1978	1979
23A	11.03	31.11	11.50		Bent by ice
B	4.22	8.26	3.13		Bent by ice
C	0.26	0.845	1.88	3.5	Bent by ice
24A	22.50	50.0	Handles Broken	Connection Broken	Bent by ice
B	4.29	4.77	2.50	Connection Broken	Bent by ice
C	0.48	1.06	1.50	2.22	Bent by ice
25A	---	---	---		Bent by ice
B	---	---	---		Bent by ice

*Initial Potential Reading <-0.85 V (Potential was not shifted by 150 mV).

Because of this error, the rate of coating degradation at Buzzards Bay cannot be determined by electrical methods. However, the error in measurements was corrected in 1979, the measurements in 1980 should give the rate of the coatings' degradation.

Icing conditions were severe in the winter of 1977 and 1978. Concrete pilings were completely broken in 1977, and steel piles 18 through 24 were bent.

Polarization Measurements

The corrosion rate or rate of metal loss can be determined from the average corrosion current density: the higher the corrosion current density, the higher the metal loss or the corrosion rate.[10] In 1979, the corrosion current (as calculated from Eq 2) for bare carbon-steel pile 1A was 0.8 amp, and for Mariner steel pile 4A, also 0.8 amp (Figure 8 and Figure 9). I_p and I_q were determined by extending the tangents of linear portions of the curves and determining their intersection, as shown in Figures 8 and 9.

The flange thicknesses of the bare and cathodically protected pilings are shown in Figures 10 to 15. It is observed that the average corrosion rate of bare carbon steel (A 36) in the immersed zone (excluding tidal zone) is 3.4 mils/yr. The corresponding average corrosion rate for bare Mariner steel (ASTM 690) in the immersed zone is 1.4 mils/yr. Sacrificial anodes reduced the corrosion rate to zero in the immersed zone.

Visual Observation of Coating Deterioration

The following paragraphs evaluate coatings in the immersed zone and splash zone. Charts of the coating degradation are shown in the appendix.

1. Pile 1C was bare carbon steel and was corroding, but no pitting was noted. There appeared to be some delamination of the steel at the waterline.

2. Pile 6C had an epoxy, zinc-rich primer E-303 C-200 coal tar epoxy system with attached zinc anodes. The coating appeared to be in perfect condition, and the anode was in near-new condition. The coating thickness measured about 22 mils, with some measurements as high as 28 mils.

3. Pile 7C had an epoxy, zinc-rich primer E-303 C-200 coal tar epoxy system with a coating thickness varying from 12 to 30 mils, with most thicknesses in the 20 to 30 mil range in the upper areas, and in the 16 to 18 mil range at the waterline. Several square inches of corrosion were noted at the waterline; where a handle had been welded to the pile. Poor surface preparation may have been responsible for the rust. In addition, the primer adhered poorly to the steel within about 1-1/2 in. (3.81 cm) of this corrosion. No other coating defects were noted.

4. Pile 8C had a Porter #352 Zinc Loc zinc-rich primer/C-200 coal tar epoxy system. Thickness was about 17 to 18 mils in the waterline area, with a few areas as thin as 13 mils. Other than damage done to the top of the pile by the driving operation, the coating appeared to be in perfect condition.

5. Pile 9C was a zinc-rich primer E-303/C-200 coal tar epoxy system with aluminum oxide grit added to the final coat of C-200 coal tar epoxy. Thickness measurements were impractical due to the roughness of the coating system. The coating system was in excellent condition; however, the fouling was more abundant and more difficult to remove because of the system's roughness.

[10] E. Escalante, et al., NBSIR 76-1104.

6. Pile 10C had an epoxy resin primer manufactured by Porter, followed by a C-200 coal tar epoxy topcoat. Coating thickness at the waterline area was 19 to 25 mils, with some measurements as high as 30 mils. The system appeared to be in perfect condition.

7. Pile 11C was Mariner steel with zinc-rich primer F-303/C-200 coal tar epoxy system at a 20-mil thickness. The coating was in near-perfect condition.

8. Pile 12C was coated with a Plas Chem system consisting of a zinc-rich Zinc-ite primer, a ceramic Ceram-ite #101 intermediate coat, and a 2140Z high-build epoxy topcoat. The coating was extremely weak and had rust coming through. The system was nonexistent at the waterline, where there was heavy rusting. Coating adhesion was so poor underwater that it could be removed with the thumbnail. Thickness of the coating appeared to be about 10 mils above the waterline, and about 14 to 16 mils on underwater areas.

9. Pile 13C was coated with a Plas Chem system consisting of a Zin-cor #11 organic zinc-rich primer with Chem-Pon #2310X Red and #2310X Grey epoxy topcoats. Thickness ranged from 7 to 15 mils on underwater areas, with many measurements of 9 to 10 mils. Bare areas along the edges appeared to have been patched with coal tar epoxy. The coating was very brittle and had been knocked off the outer flange of the pile in many areas.

10. Pile 14C had a Chemglaze organic zinc-rich primer with a Chemglaze II urethane topcoat, both made by Hughson Chemicals. The coating showed extensive rust along the edges in the atmospheric areas, and associated blistering and rust undercutting. At the waterline, some areas had no topcoat, while others had no coating at all. Extremely dense #5 and #6 blisters were present on underwater areas. The coating measured 5 to 9 mils, with much of the underwater areas measuring 6 to 7 mils.

11. Pile 15C had a urethane intermediate coat and topcoat over an organic zinc primer; all coatings were manufactured by Hughson Chemicals. Some corrosion broke through the coating on flat surfaces, and the sharp corners of the piles showed corrosion due to damage. Dense #6 and #7 blisters were noted along the damaged edges on underwater areas. Coating thickness measured 15 to 17 mils.

12. Pile 16C had a flame-sprayed zinc primer followed by a blue MIL-P-15328 wash primer, and a Urecal 9301 polyurethane. The coating was densely blistered, with many blisters in the 3/4- to 1-in (1.91 to 2.54 cm) diameter size on the underwater areas. Loss of adhesion occurred between the wash primer and the flame-sprayed zinc. There were areas at or slightly above the upper waterline, and carbonates inside the blisters.

13. Pile 17C had a flame-sprayed aluminum system, which was gone in the web area at the top of the splash zone. The adjacent flat surfaces had large peeling and blistering areas.

14. Pile 18C had a flame-sprayed aluminum primer with a blue MIL-P-15328 wash primer and a Metcoseal Aluminum Vinyl Sealer. On the upper portion of the pile, there were 2- to 6-in. (5.08 to 15.24 cm)-wide lines of corrosion or blistering crossing the piling and spaced at about 2-ft (0.6m) intervals along the pile. These were probably caused by an application defect. Extensive blistering and the blue wash primer could be seen at many places along the waterline. However, the edges of the steel piling were still rectangular because of the galvanic cathodic protection.

15. Pile 19C was primed with flame-sprayed zinc, coated with a coal-tar solution, and topcoated with a coal-tar emulsion. There were dense #4 blisters on all underwater areas, with extensive rusting in the splash zone. In the upper splash area, as much as 75 percent of the steel was bare and rusting. Atmospheric areas were in fair to poor condition, with minor rusting along some edges and extensive #4 blistering. The coating was extremely weak and crumbled when scratched with a jack-knife. Coating thickness above the waterline was 22 to 23 mils.

16. Pile 20C had a vinyl zinc with a vinyl glass flake VZ-108/V-110 vinyl paint system. The coating had dense #4 blisters on all underwater areas. There was almost no rust on underwater areas; however, some bare edges were rusting along the waterline. No rust undercutting was noted along the rusting edges.

17. Pile 21C had an inorganic zinc Dimetcoat #3, a synthetic resin Amercoat #54 tiecoat, and a #87 vinyl mastic topcoat. The pile was bent sharply at ground level; the coating had shattered in that area, leaving the pile completely bare. There were medium-dense #6 blisters in the upper portion of the splash area. Some of the blisters were cracked and allowed the underlying steel to rust. Many of the edges of the pile were bare and rusting. Coating thickness measured about 9 to 10 mils.

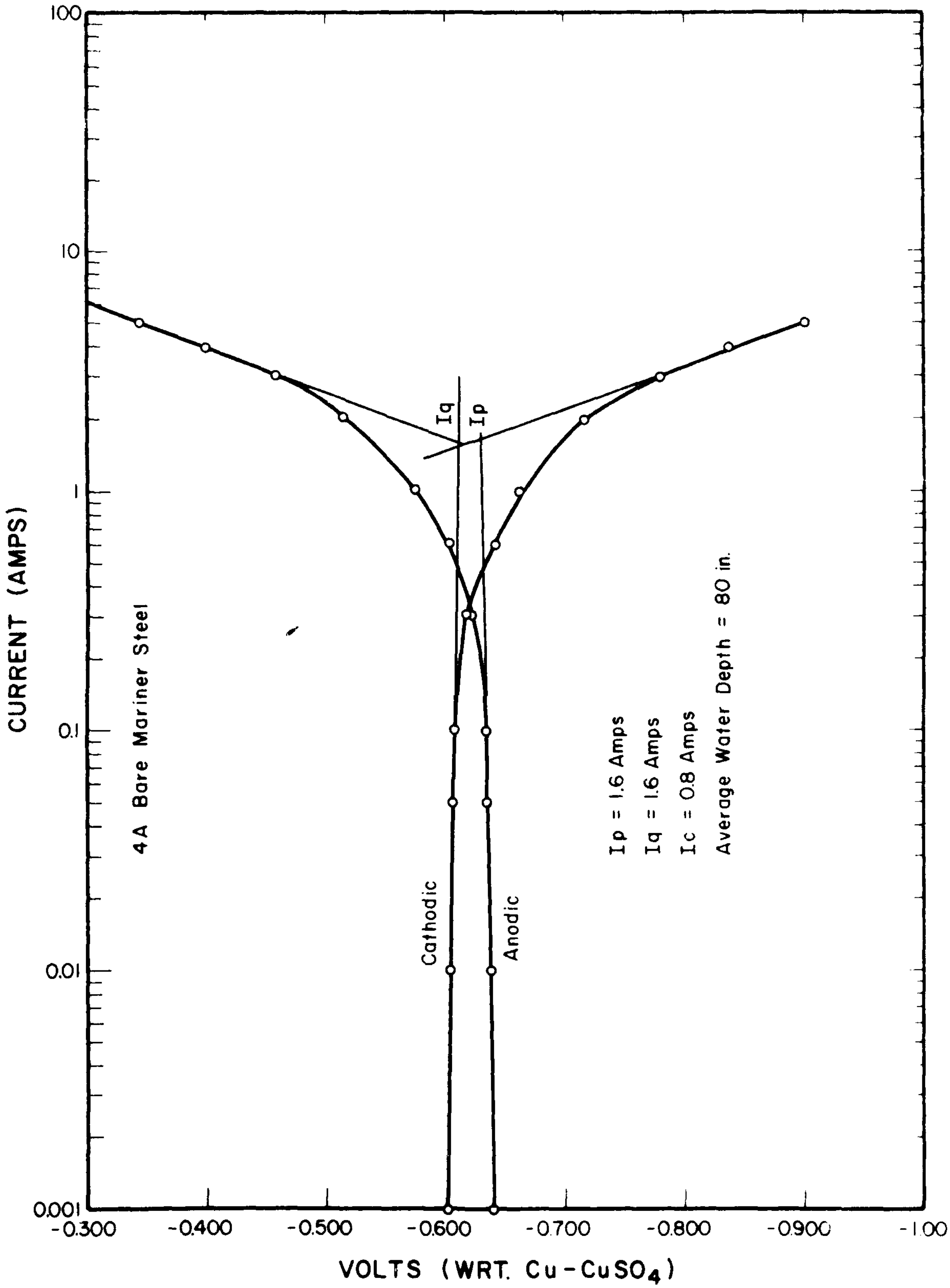

Figure 8. Polarization characteristics of bare carbon steel (ASTM A 36).

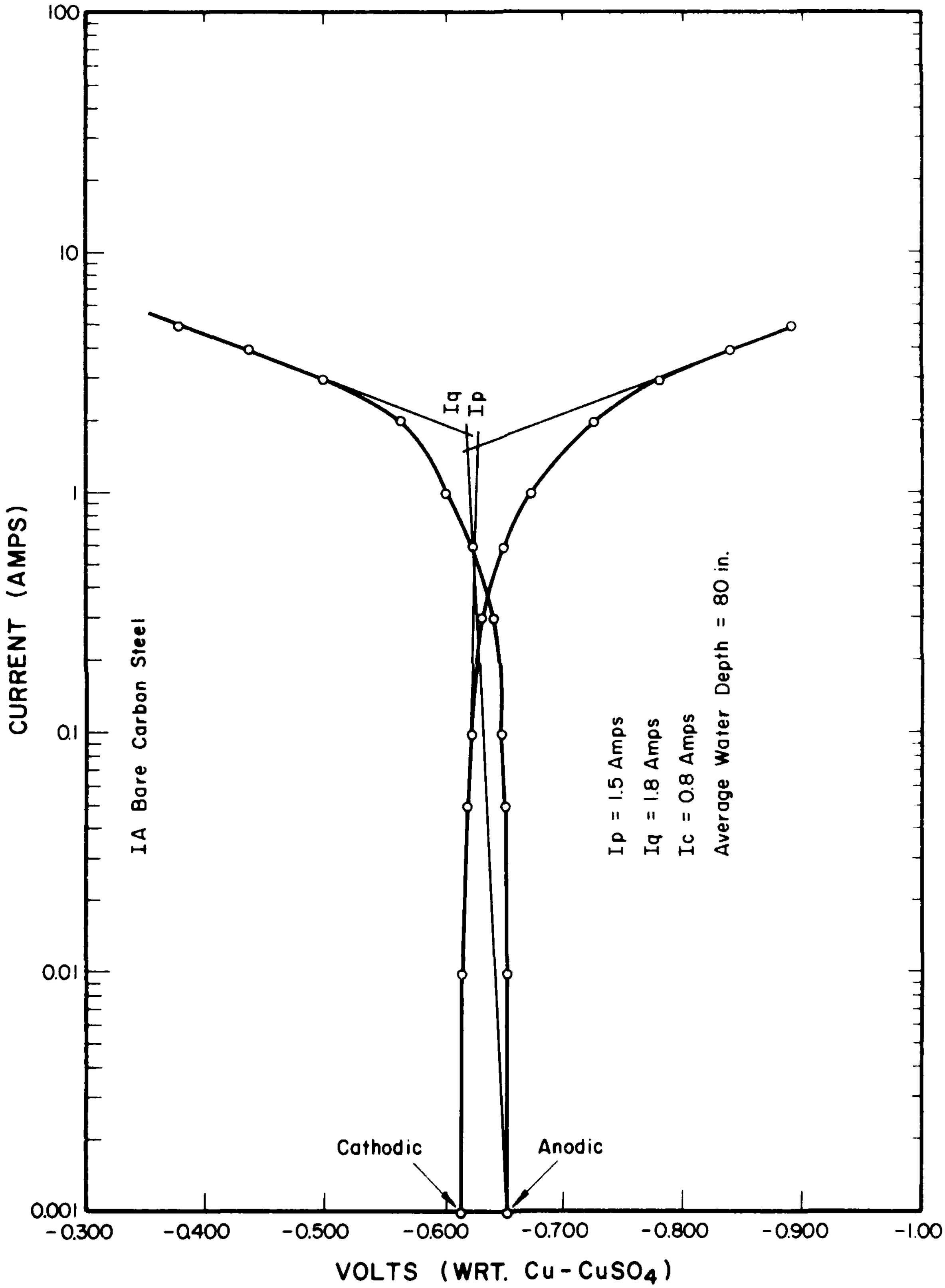

Figure 9. Polarization characteristics of bare Mariner steel (ASTM 690).

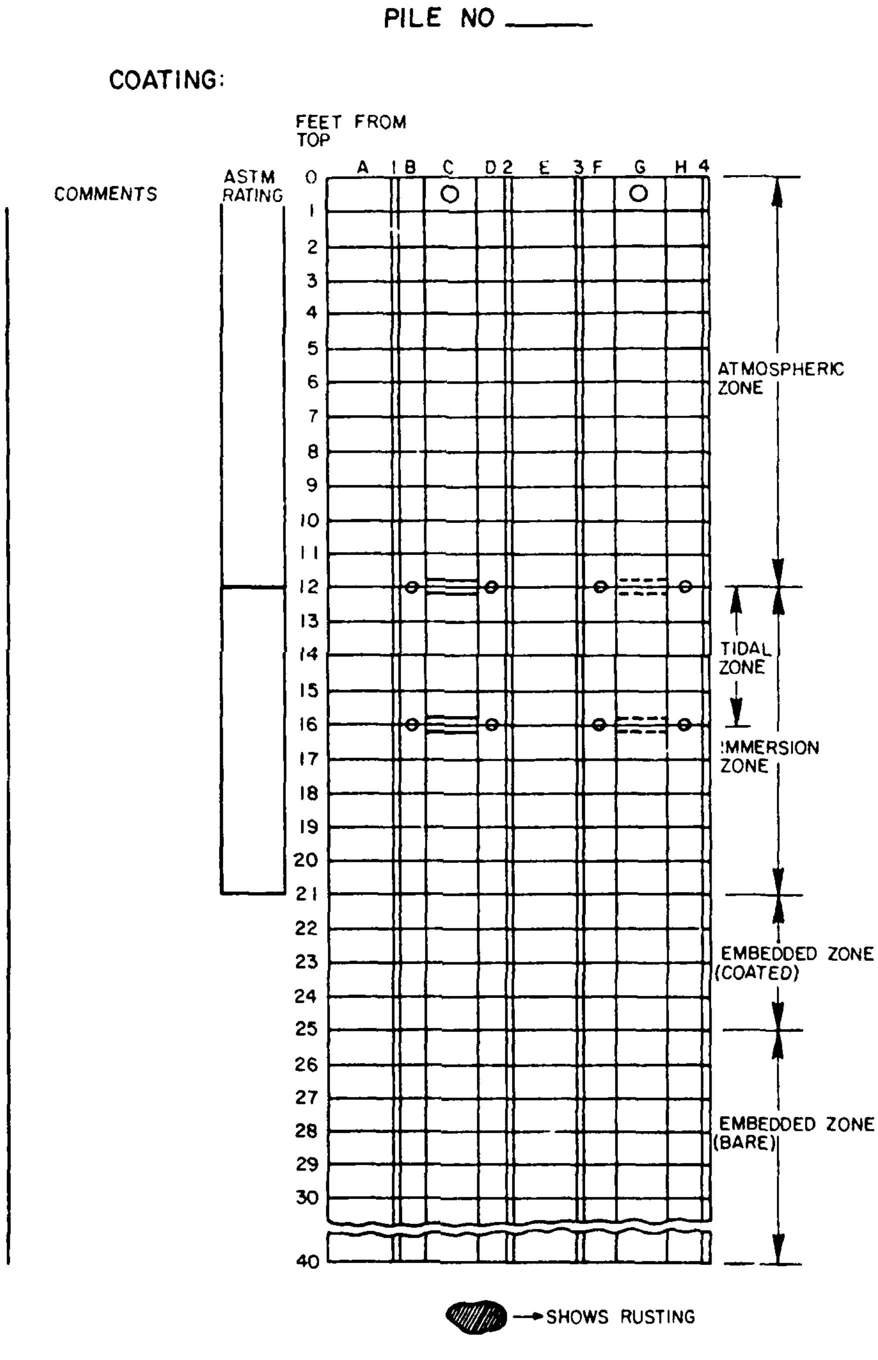

Figure 10. Typical schematic surface area of pilings showing various zones.

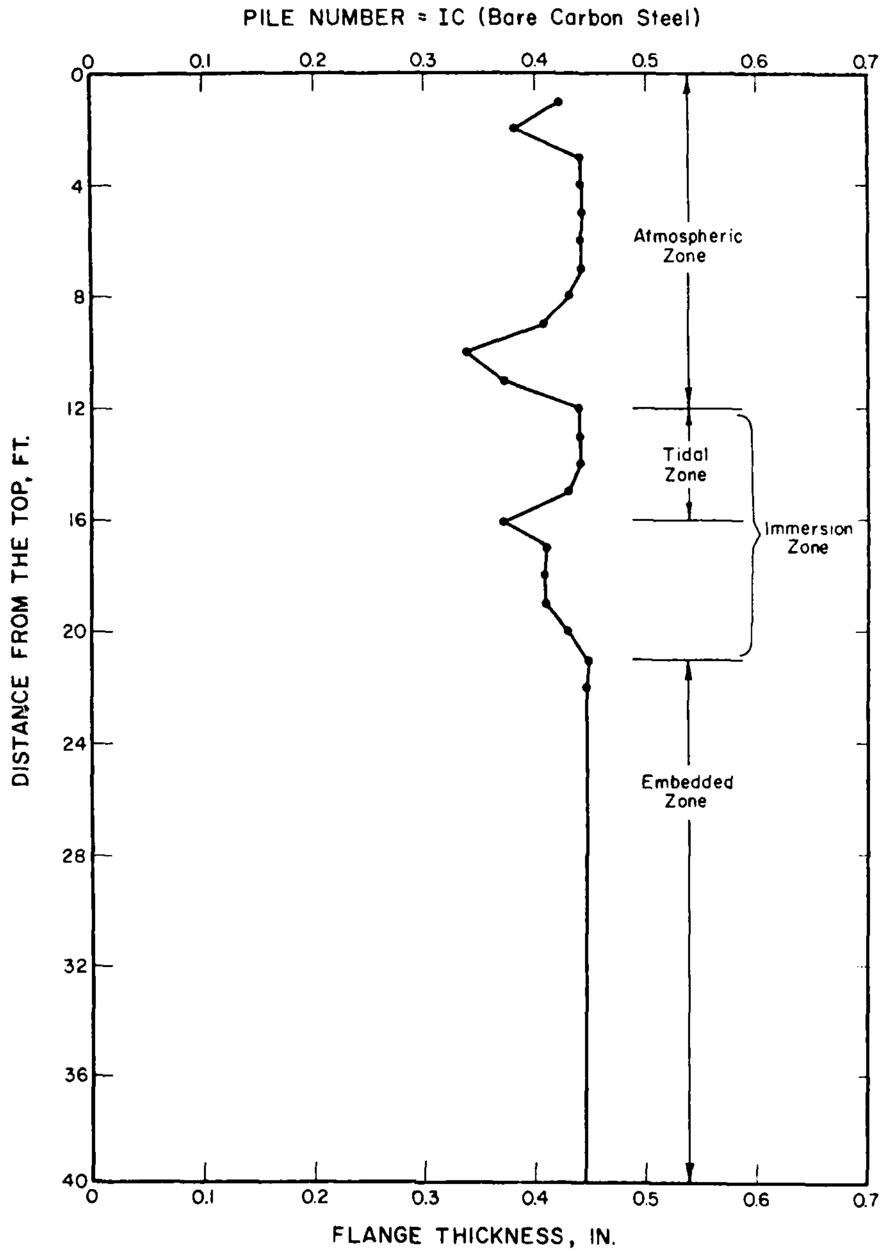

Figure 11. The flange thickness of bare carbon steel (ASTM A 36) pile at various depths.

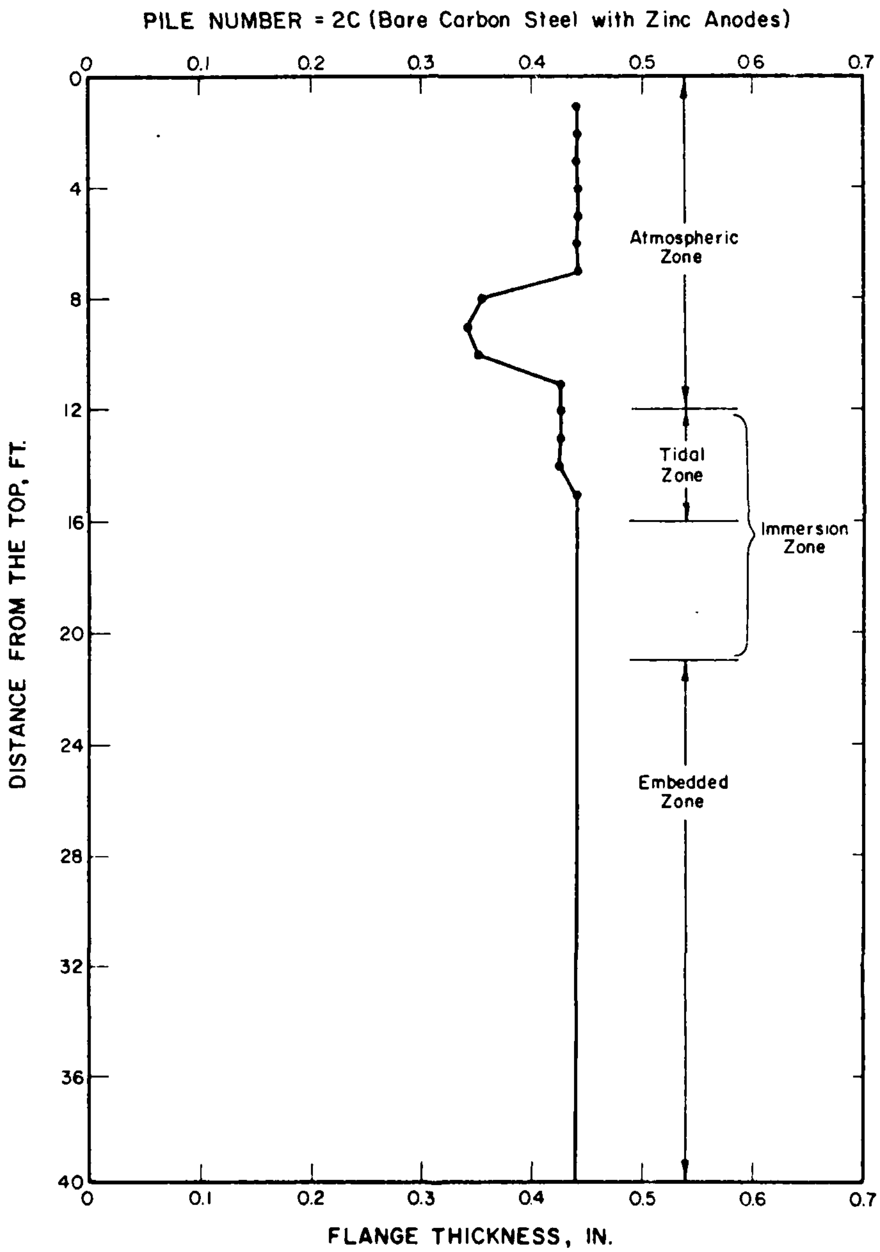

Figure 12. The flange thickness of bare carbon steel (ASTM A 36) pile with sacrificial zinc anodes at various depths.

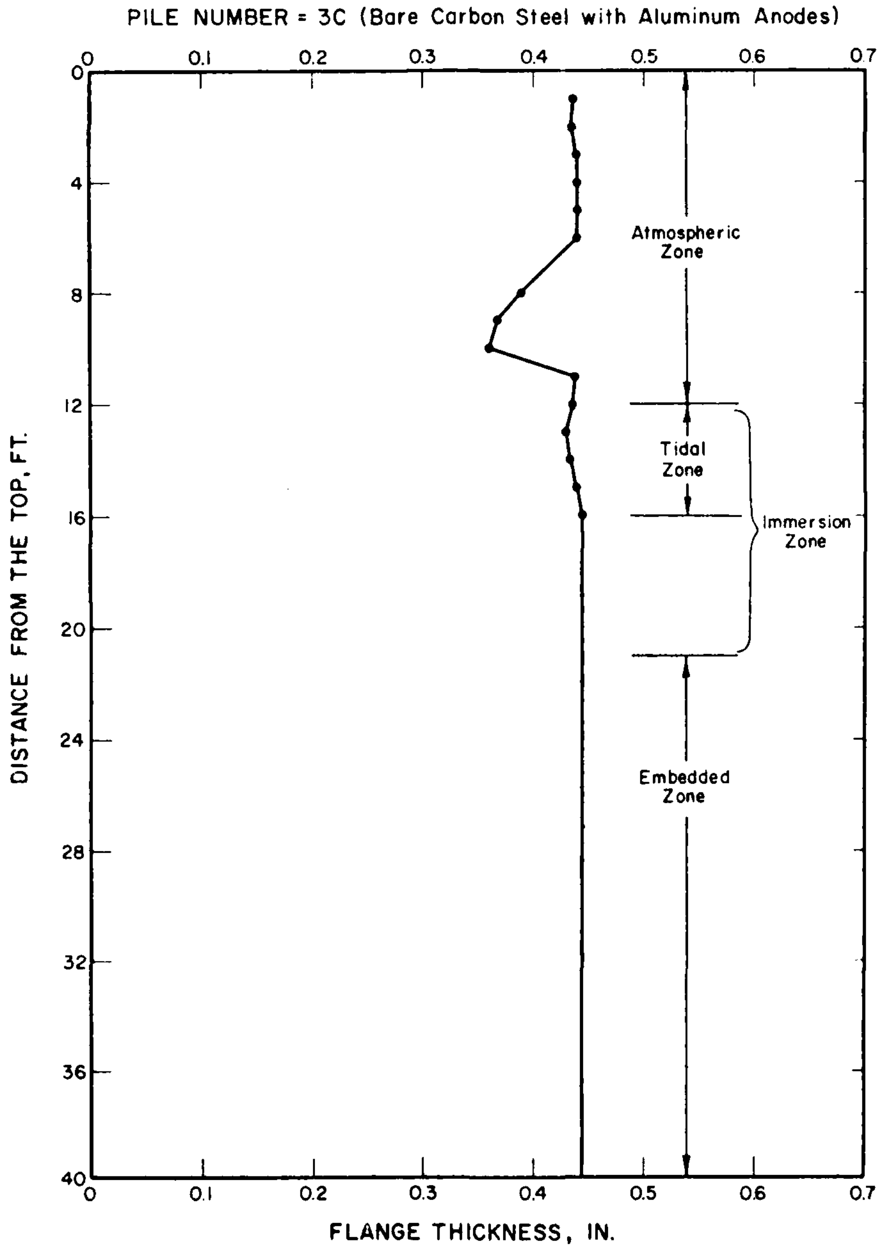

Figure 13. The flange thickness of bare carbon steel (ASTM A 36) pile with sacrificial aluminum anodes at various depths.

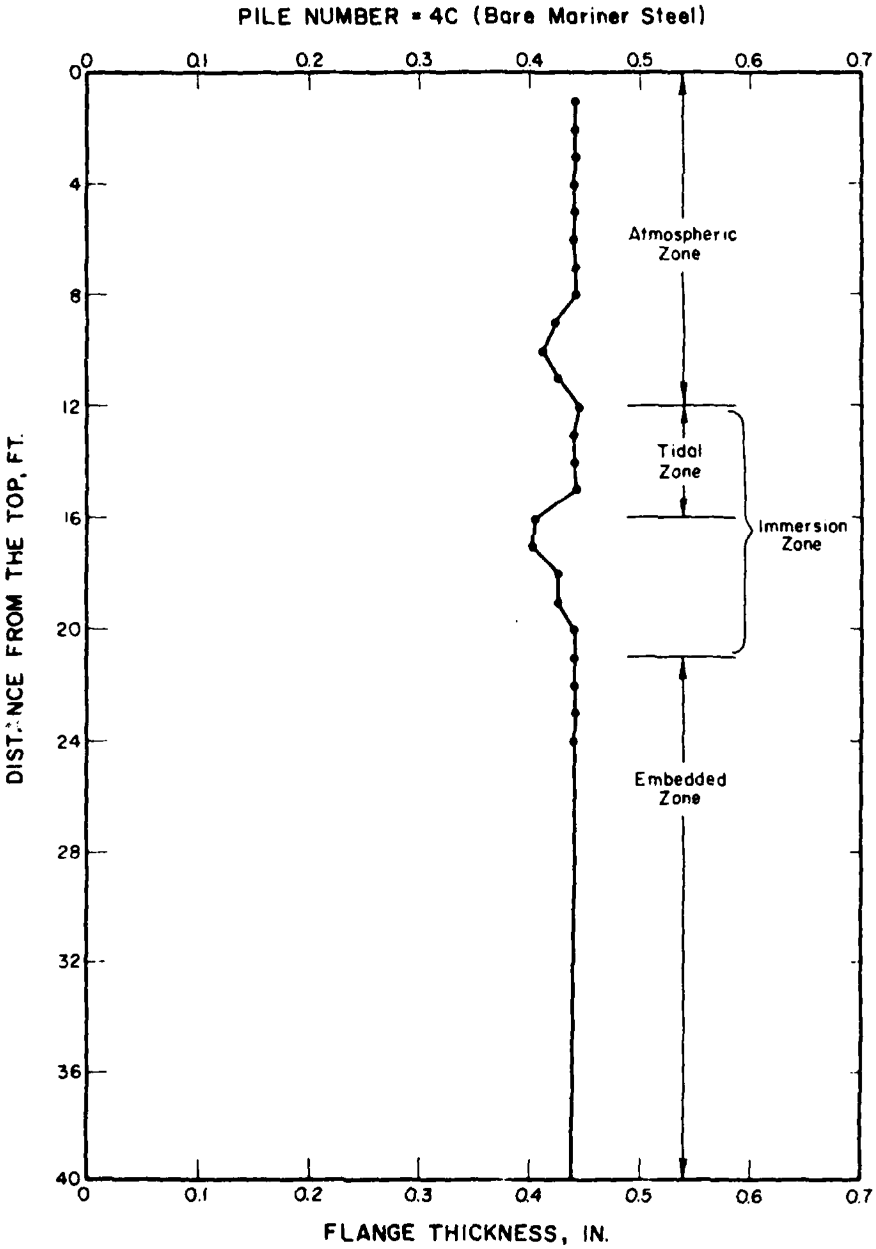

Figure 14. The flange thickness of bare Mariner steel (ASTM 690) pile at various depths.

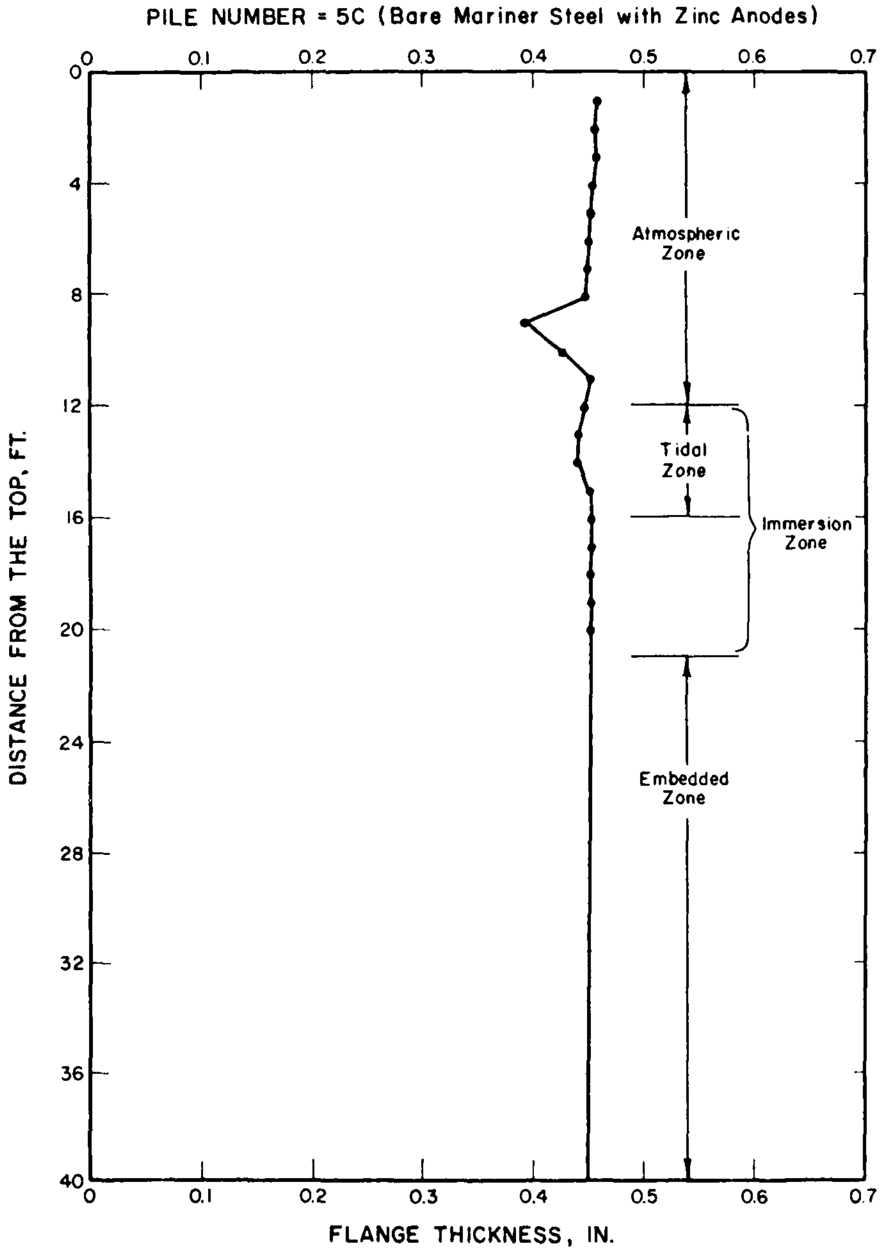

Figure 15. The flange thickness of bare Mariner steel (ASTM 690) pile with sacrificial zinc anodes at various depths.

Table 5

Visual Evaluation of Coated Steel Piles After 5-Year Exposure at Buzzards Bay, MA, According to ASTM D 610-68

Coating System		ASTM Rating	
Number	Generic Classification	Atmospheric Zone 29–40 ft	Immersed Zone 20–29 ft
6	Coal Tar Epoxy Over Zinc-Rich + Anodes	10	10
7	Coal Tar Epoxy Over Zinc-Rich	9	9
8	Coal Tar Epoxy Over Zinc-Rich	8	9
9	Coal Tar Epoxy Over Zinc-Rich + Al_2O_3	8	9
10	Coal Tar Epoxy Over Epoxy Resin	9	9
11	Coal Tar Epoxy Over Zinc-Rich Over Mariner	8	9
12	Epoxy Over Inorganic Ceramic	5	0
13	Epoxy Over Organic Zinc Primer	8	5
14	Polyurethane Over Organic Zinc-Rich	8	6
15	Polyurethane Over Organic Zinc-Rich + Elastomeric	8	8
16	Polyurethane Over Flame Sprayed	4	0
17	Aluminum, Flame Sprayed	1	1
18	Aluminum, Flame Sprayed + Vinyl Sealer	8	8
19	Zinc, Flame Sprayed With Coal Tar Emulsion	6	0 (Bent by ice)
20	Vinyl Glass Flake Over Vinyl Zinc-Rich	8	8 (Bent by ice)
21	Vinyl Mastic Over Resin	3	4 (Bent by ice)

Categories of Coatings

For discussion, the coatings for these 17 pilings can be divided into five categories:

1. Organic coatings
2. Organic over metal-filled coatings
3. Organic over metal-filled coatings with cathodic protection
4. Metallic coatings
5. Organic over metallic coatings.

These classes are discussed below; the coatings' ASTM ratings are summarized in Table 5.[11] (Table 2 describes the numerical ASTM ratings.)

Organic Coatings (Systems 10, 12, and 21)

System 10, a coal tar epoxy C-200 over epoxy resin primer, gave good protection and was rated 9 in the immersed zone. At this time, coal tar coatings are readily available. However, coal tar pitches used in these coatings contain compounds which are known carcinogens. SSPC is investigating complaints by user agencies about the continued use of coal tar coatings. Most of the damage to the coal tar epoxy coating was caused by marine organisms (especially barnacles) in the immersed zone. No erosion corrosion was noted in the sand zone. System 12, which is epoxy over inorganic ceramic, was damaged during installation and did not perform well. It was rated 0 in the immersed zone. System 21, a vinyl mastic over synthetic resin tiecoat over washcoat inorganic zinc primer was blistering and given a rating of 4 The pile was bent by ice in 1978.

Organic Over Metal-Filled Coatings (Systems 7, 8, 9, 11, 13, 14, 15, and 20)

Seven coatings with electrically insulating topcoats fell into this classification. The coal tar epoxy over zinc-rich primer coatings (systems 7, 8, 9, and 11) exhibited excellent protection in the atmospheric and immersed zones. System 9 was armored at the sand zone with aluminum oxide. System 11 was on Mariner steel. There was no measurable difference between the performance of E-303 zinc-rich primer and Porter Zinc Loc primer.

System 13, an epoxy over an organic zinc-rich primer was rated 5 in the immersed zone. The epoxy

[11] *Evaluating Degree of Rusting on Painted Steel Structures*, ASTM D 610-68 (American Society for Testing and Materials, 1968).

was brittle and chipped at the edges in the atmospheric zone. System 14, a polyurethane over an organic zinc-rich primer was blistering. The topcoat was flaking and peeling in the splash zone. System 15, a polyurethane over organic zinc-rich primer with an elastomeric coat was better, but still blistered and was very easy to peel off. System 20, a vinyl glass flake for vinyl zinc, was rated 8 in the immersed zone. The pile was bent and #4 blisters were present.

Organic Over Metal-Filled Coatings With Cathodic Protection (System 6)

System 6 was coal tar epoxy over zinc-rich primer with zinc anodes. The system was virtually undamaged. It was rated 10 in the immersed zone.

Metallic Coatings (System 17)

Only System 17, a flame-sprayed aluminum, came under the metallic classification. Visually, this coating displayed significant rusting in all three zones; but on coating removal, the surface dimensions were not reduced and the edges were maintained, indicating that the coating offered sacrificial cathodic protection.

Organic Over Metallic Coatings (Systems 16, 18, and 19)

Systems 16 and 19 polyurethane and coal-tar emulsion over flame-sprayed zinc did not perform in the immersed zone and were rated 0. However, System 18, a flame-sprayed aluminum with a vinyl sealer, performed well, but was rated 8 because of the rusty spots. The edges of the pile were perfectly maintained because of the sacrificial cathodic protection provided by aluminum.

4 CONCLUSIONS

The following conclusions are based on the 5-year results at Buzzards Bay:

1. Sacrificial anodes of zinc and aluminum effectively reduced the average corrosion of carbon steel (A 36) in the immersed zone from 3.4 mils/yr to zero. The average corrosion rate of Mariner steel (ASTM 690) in the immersed zone was 1.4 mils/yr.

2. Coal tar epoxy over zinc-rich primer was the best performing coating with an ASTM rust-grade rating of 10. Coal tar epoxy over zinc-rich primer with zinc anodes for cathodic protection had the added capability of protecting the steel in the immersed zone should the coating be damaged. Vinyl glass flake over vinyl zinc-rich, flame-sprayed aluminum with vinyl sealer, and polyurethane with elastomeric topcoat over organic zinc also performed well. These coatings were rated 8 on the ASTM scale in the immersion zone.

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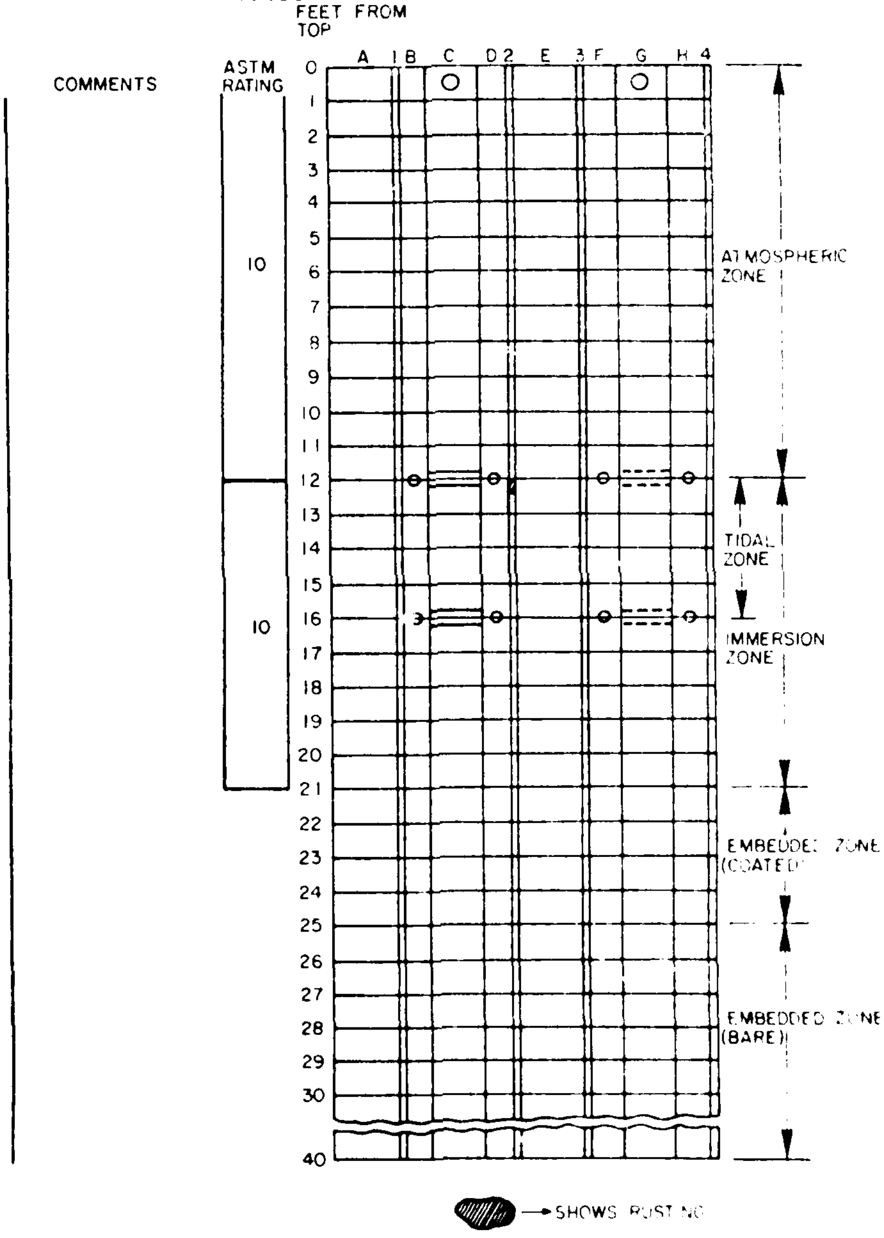
APPENDIX:
CHARTS OF CORROSION BEHAVIOR OF STEEL PILINGS
AT BUZZARDS BAY, MA, AFTER 5 YEARS OF EXPOSURE

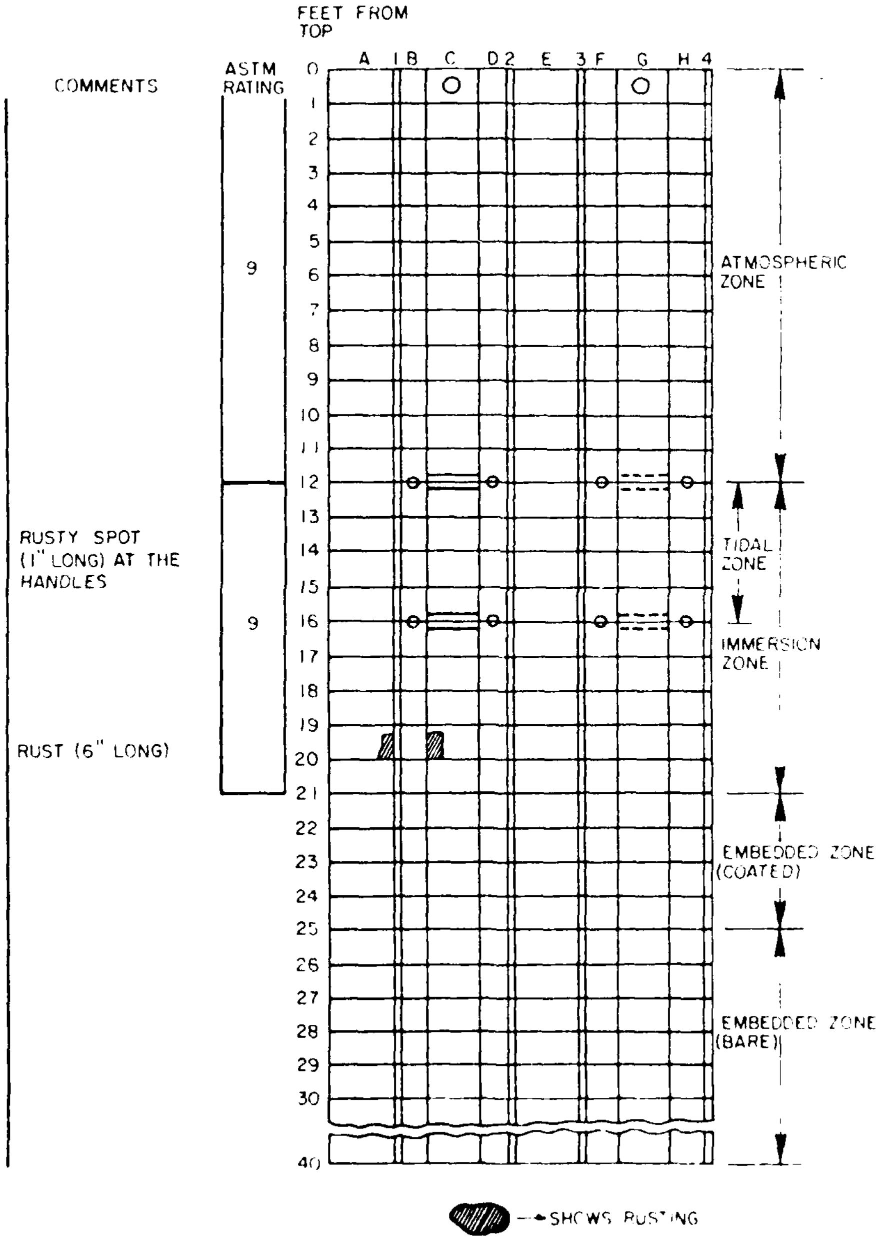
PILE NO 6C

COATING: COAL TAR EPOXY OVER ZINC RICH WITH ZINC ANODES



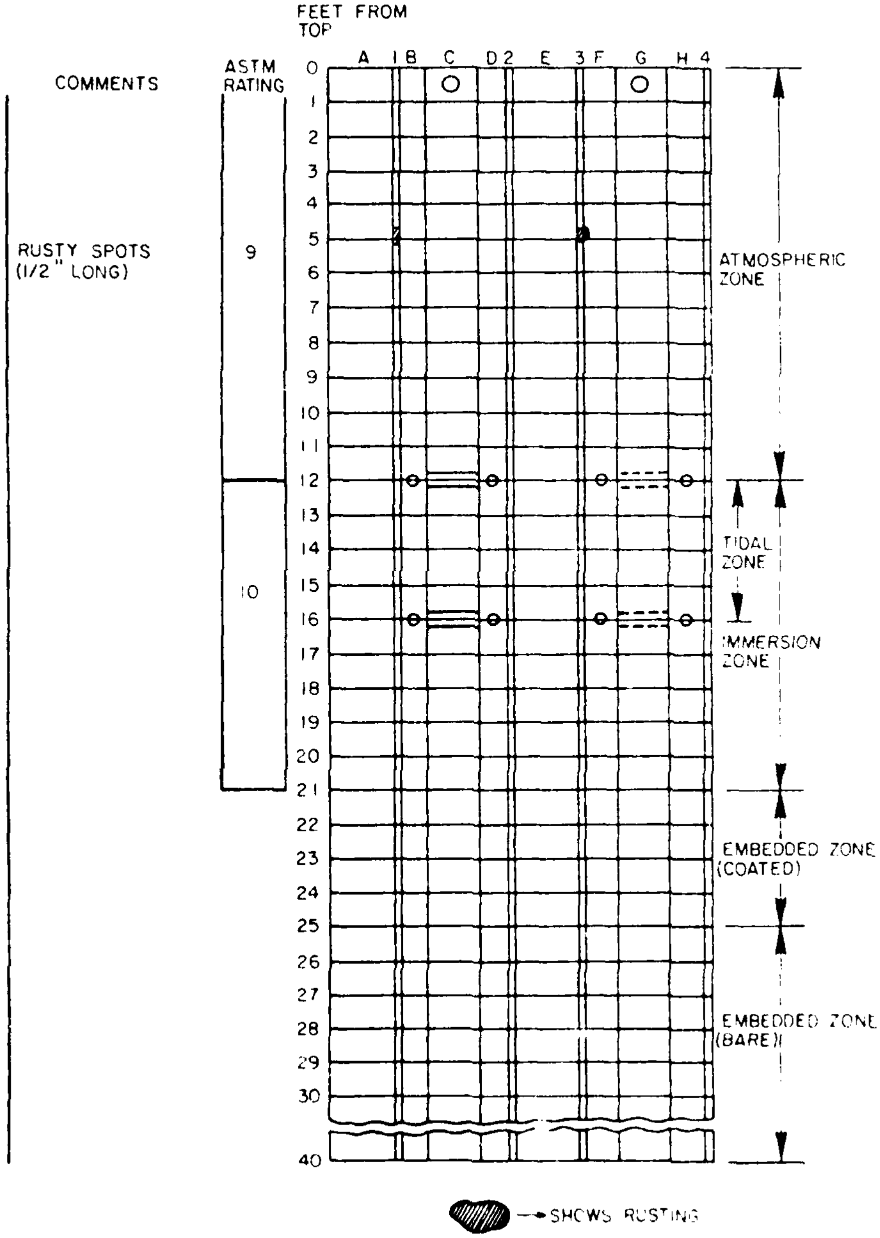
PILE NO 7C

COATING: COAL TAR EPOXY OVER ZINC RICH



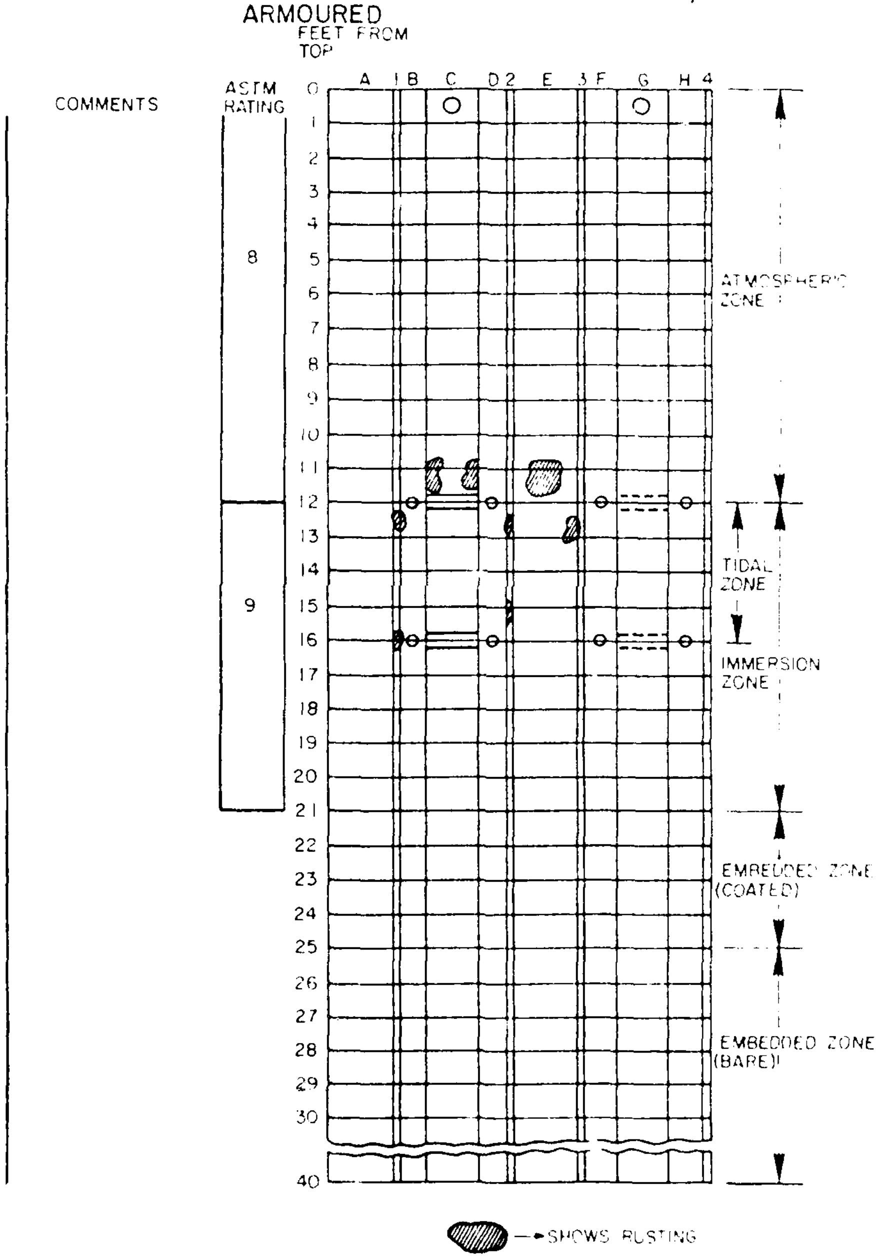
PILE NO 8C

COATING: COAL TAR EPOXY OVER ZINC RICH



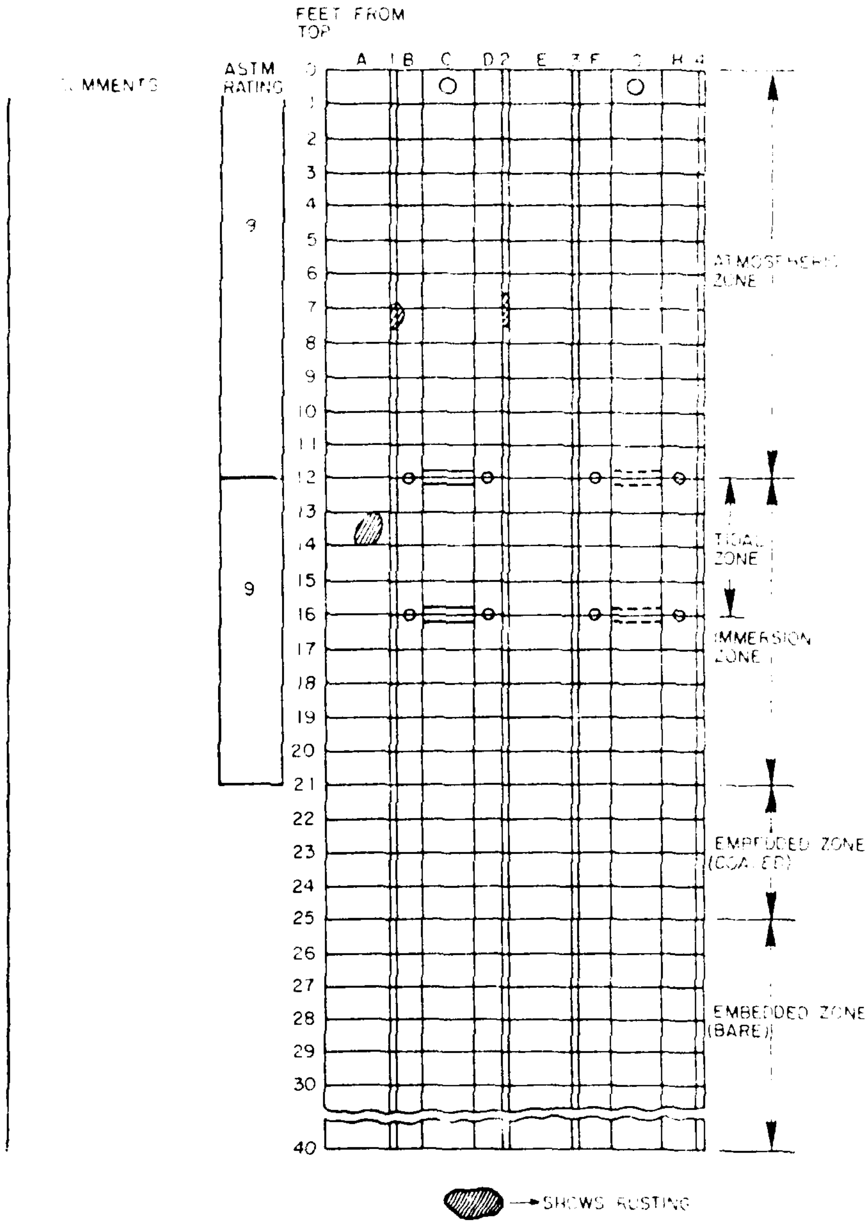
PILE NO 9C

COATING: COAL TAR EPOXY OVER ZINC RICH, ALUMINUM ARMOURED



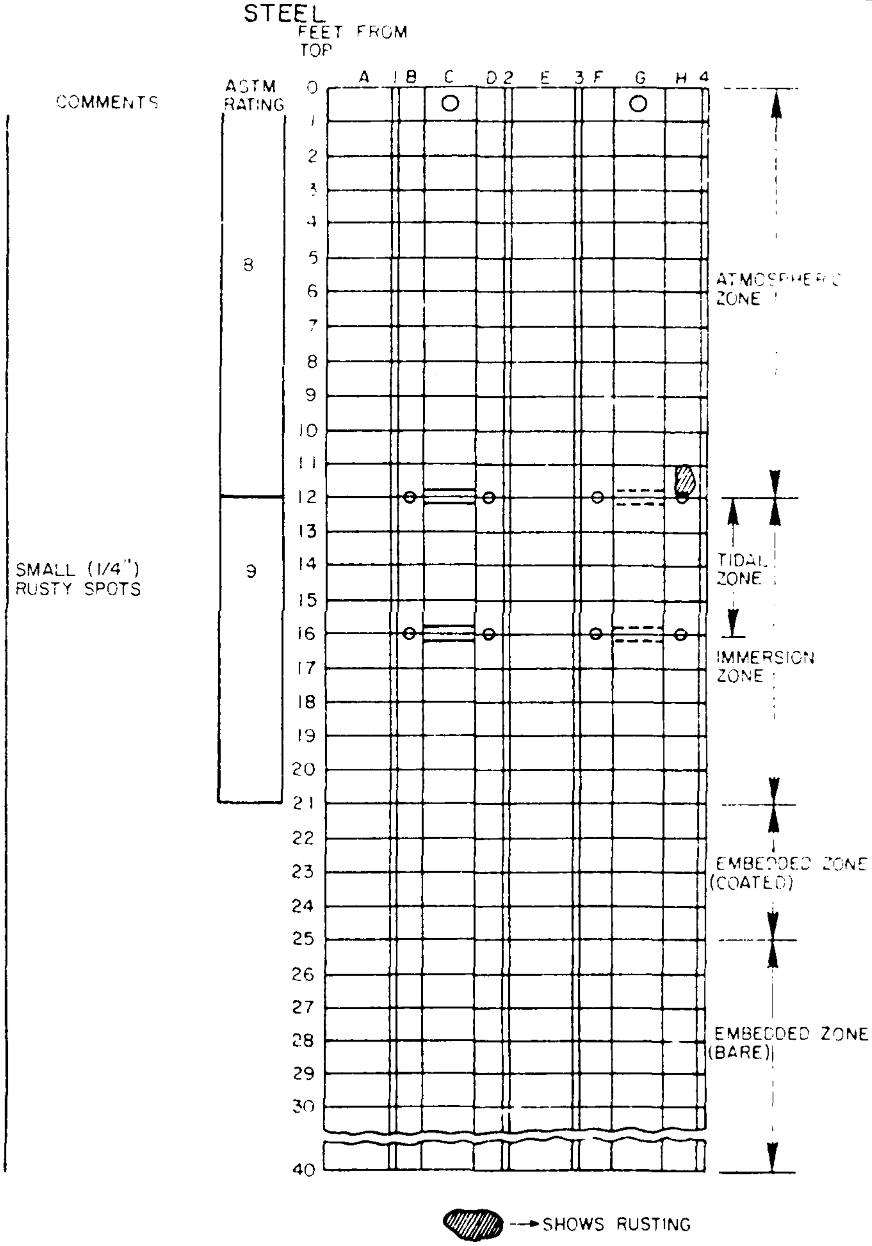
PILE NO 10C

COATING: COAL TAR EPOXY OVER EPOXY PRIMER



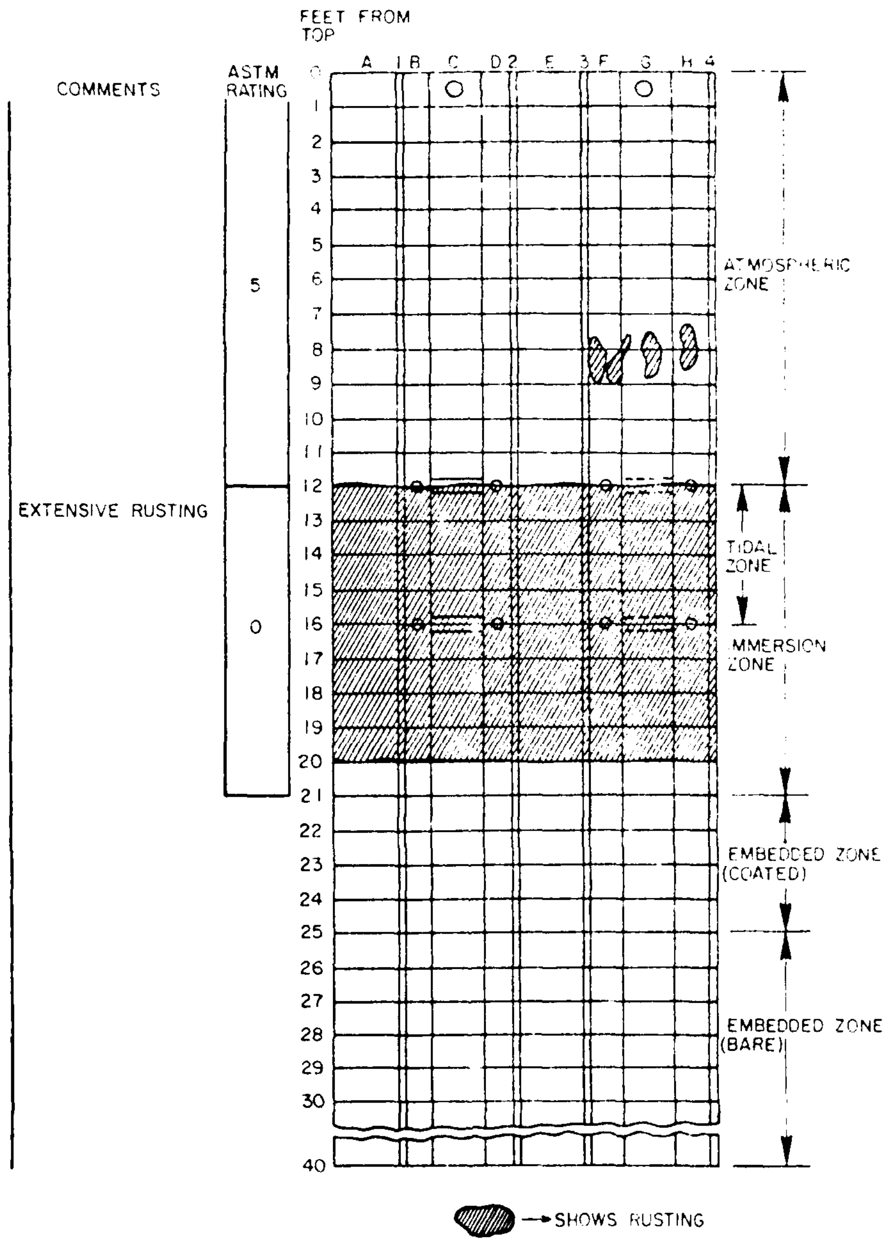
PILE NO 11C

COATING: COAL TAR EPOXY OVER ZINC RICH OVER MARINER STEEL



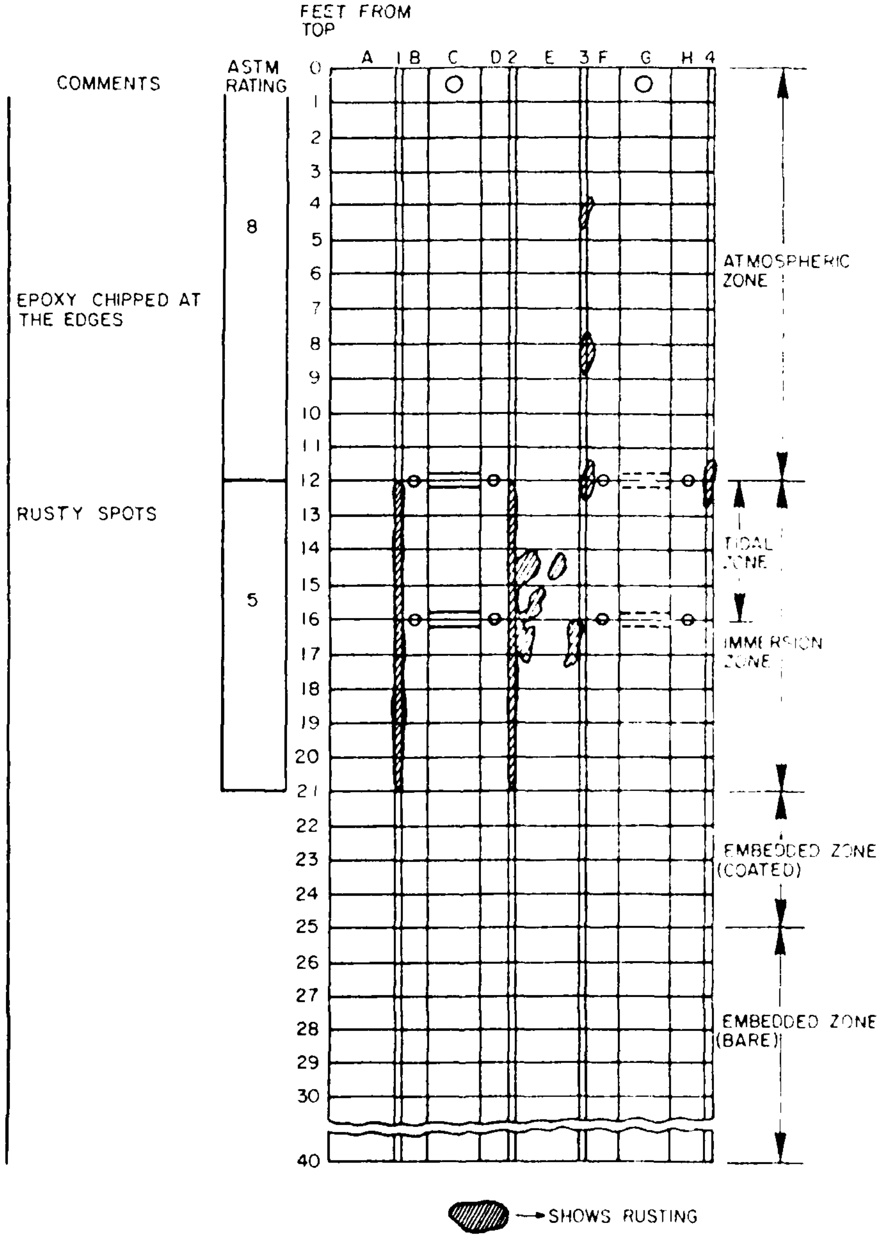
PILE NO 12C

COATING: EPOXY OVER INORGANIC CERAMIC



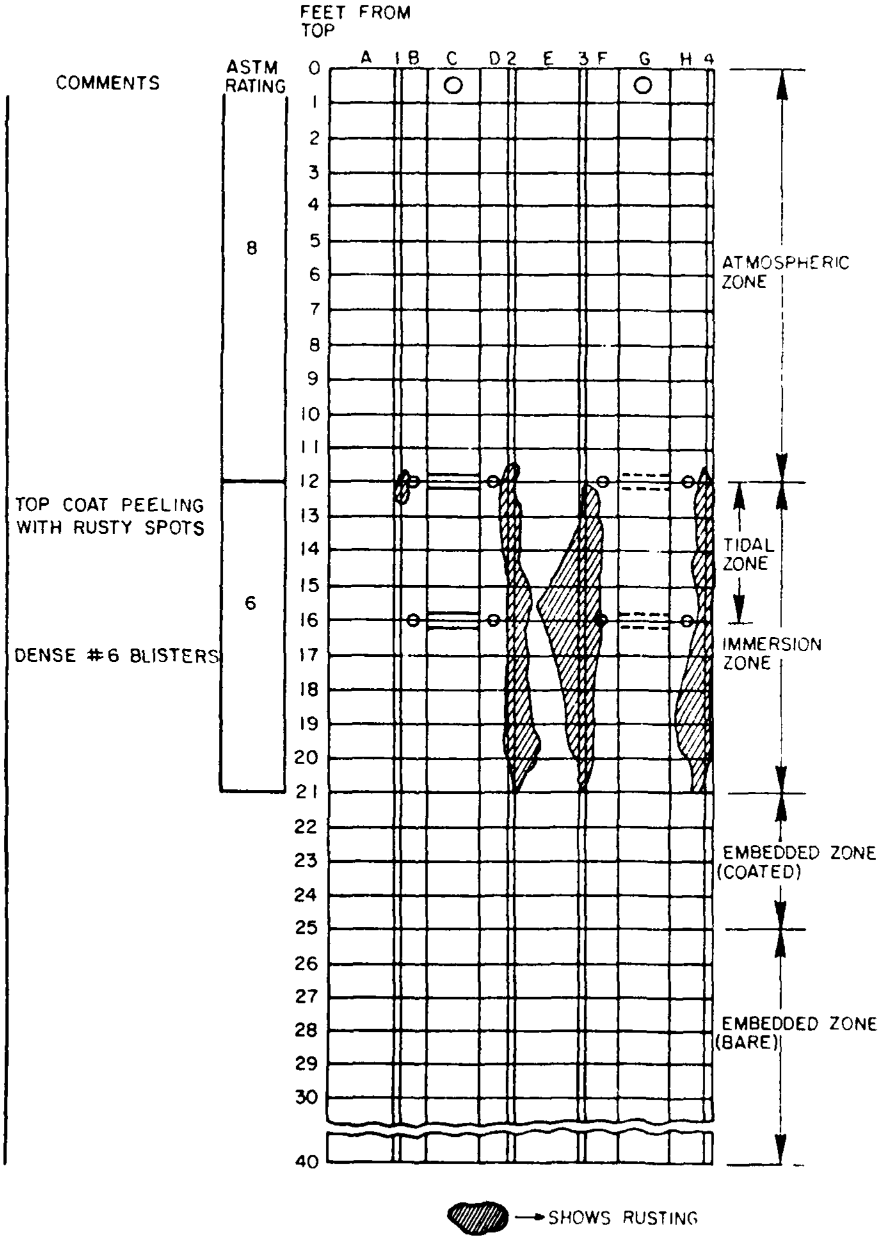
PILE NO 13C

COATING: EPOXY OVER ORGANIC ZINC



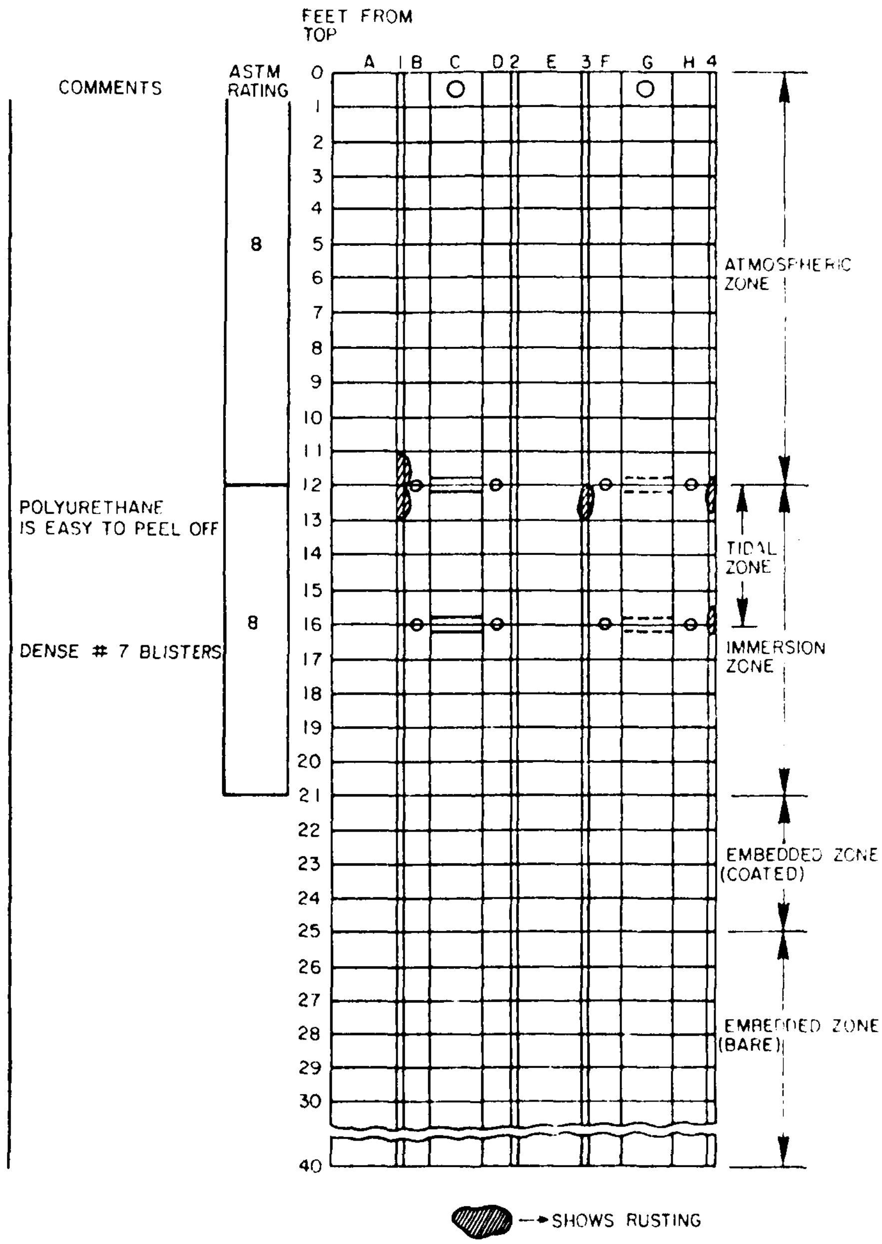
PILE NO 14C

COATING: POLYURETHANE OVER ORGANIC ZINC RICH



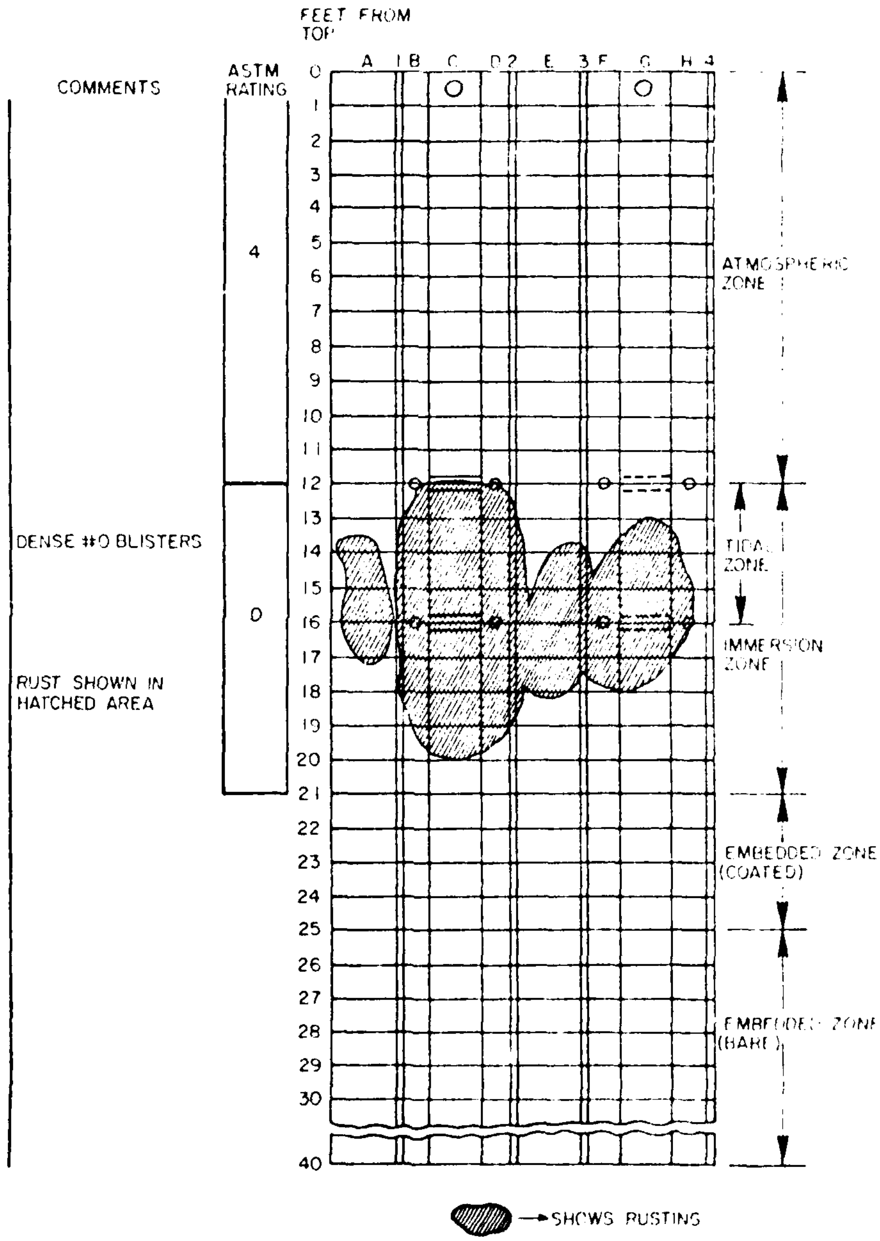
PILE NO 15C

COATING: POLYURETHANE OVER ZINC RICH



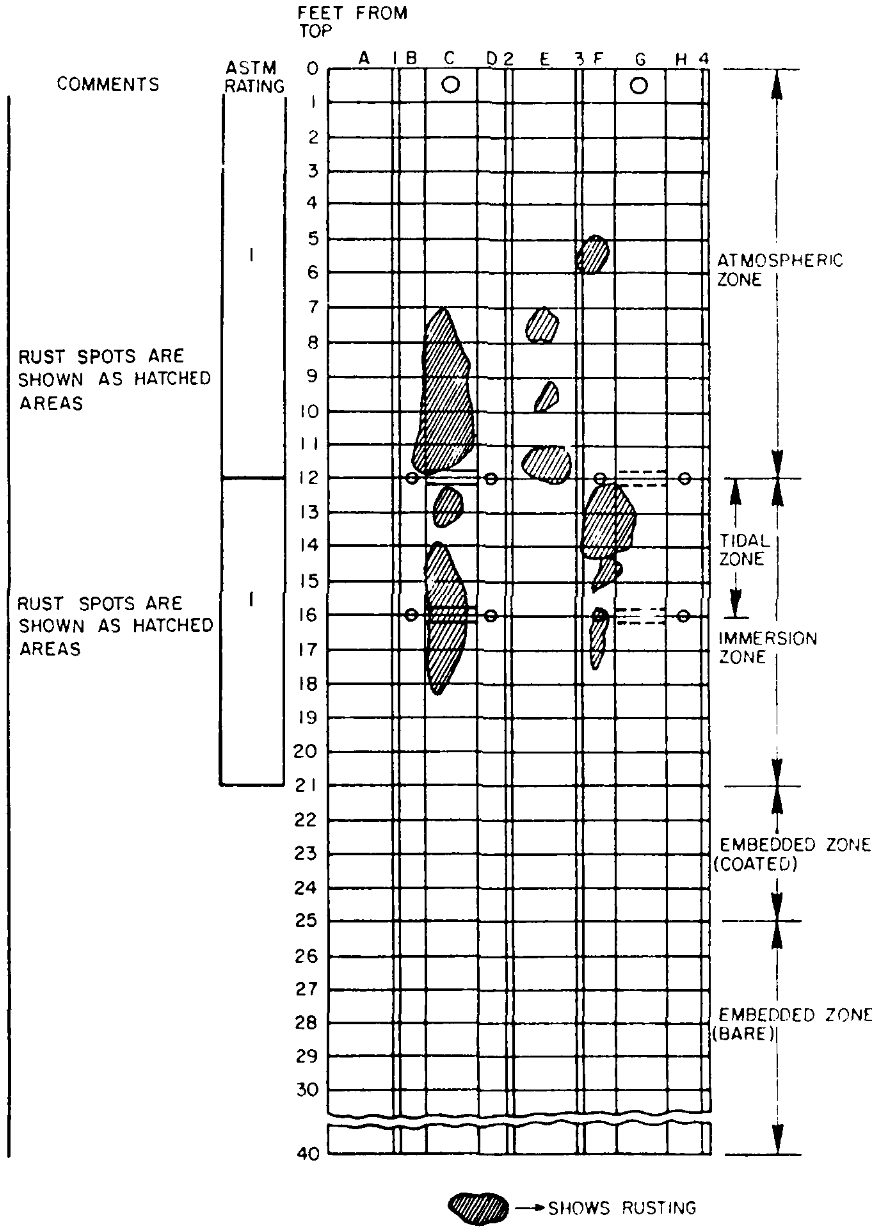
PILE NO 16C

COATING: POLYURETHANE OVER FLAME SPRAYED



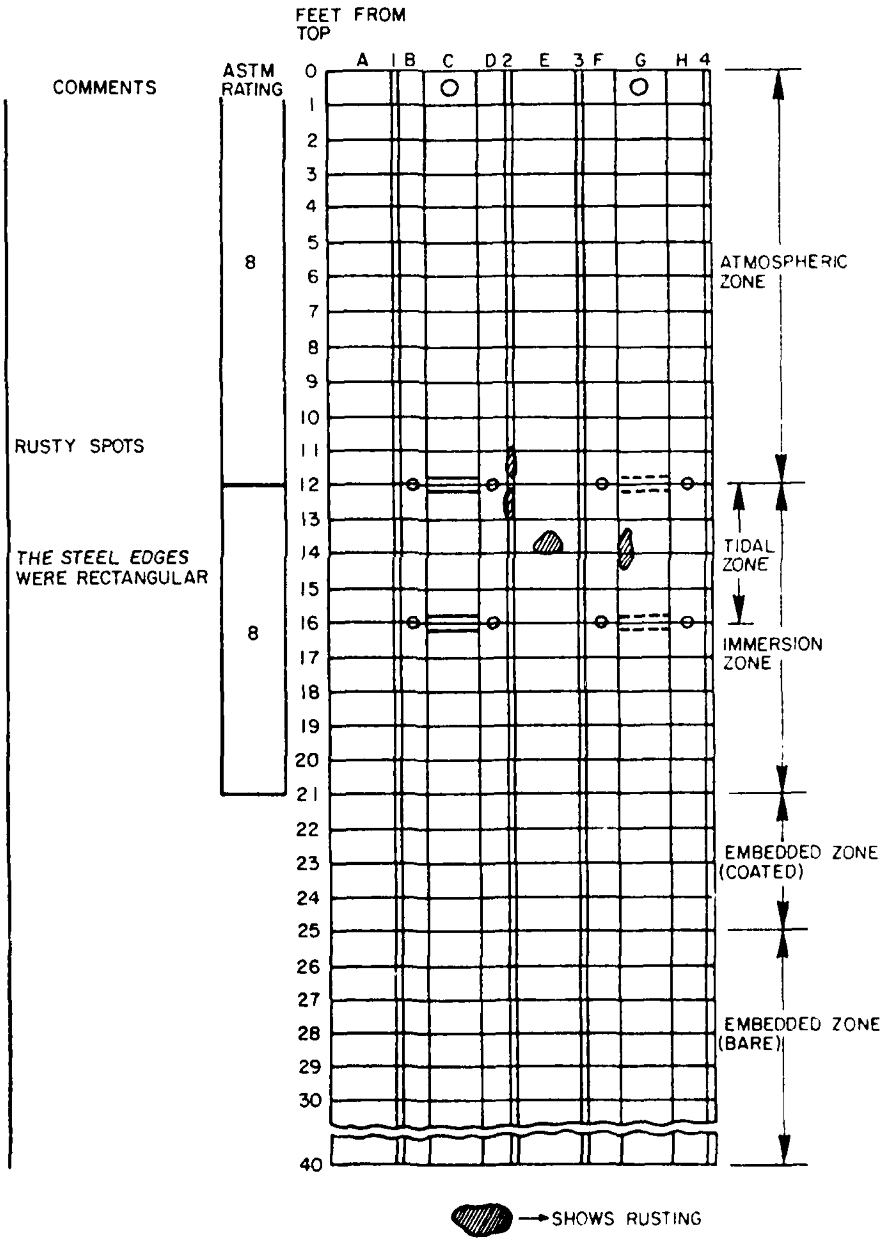
PILE NO 17C

COATING: FLAME SPRAYED ALUMINUM



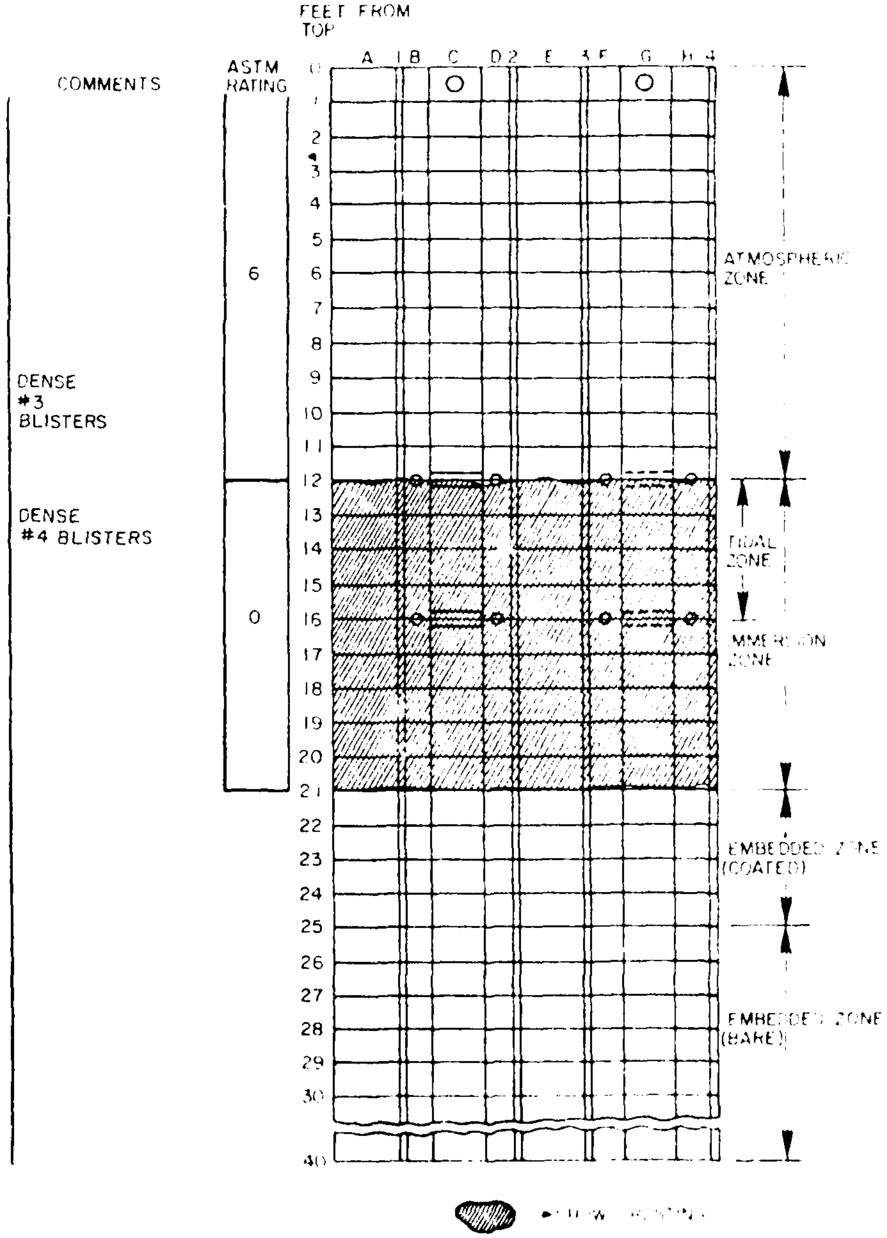
PILE NO 18C

COATING: FLAME SPRAYED ALUMINUM AND VINYL SEALER



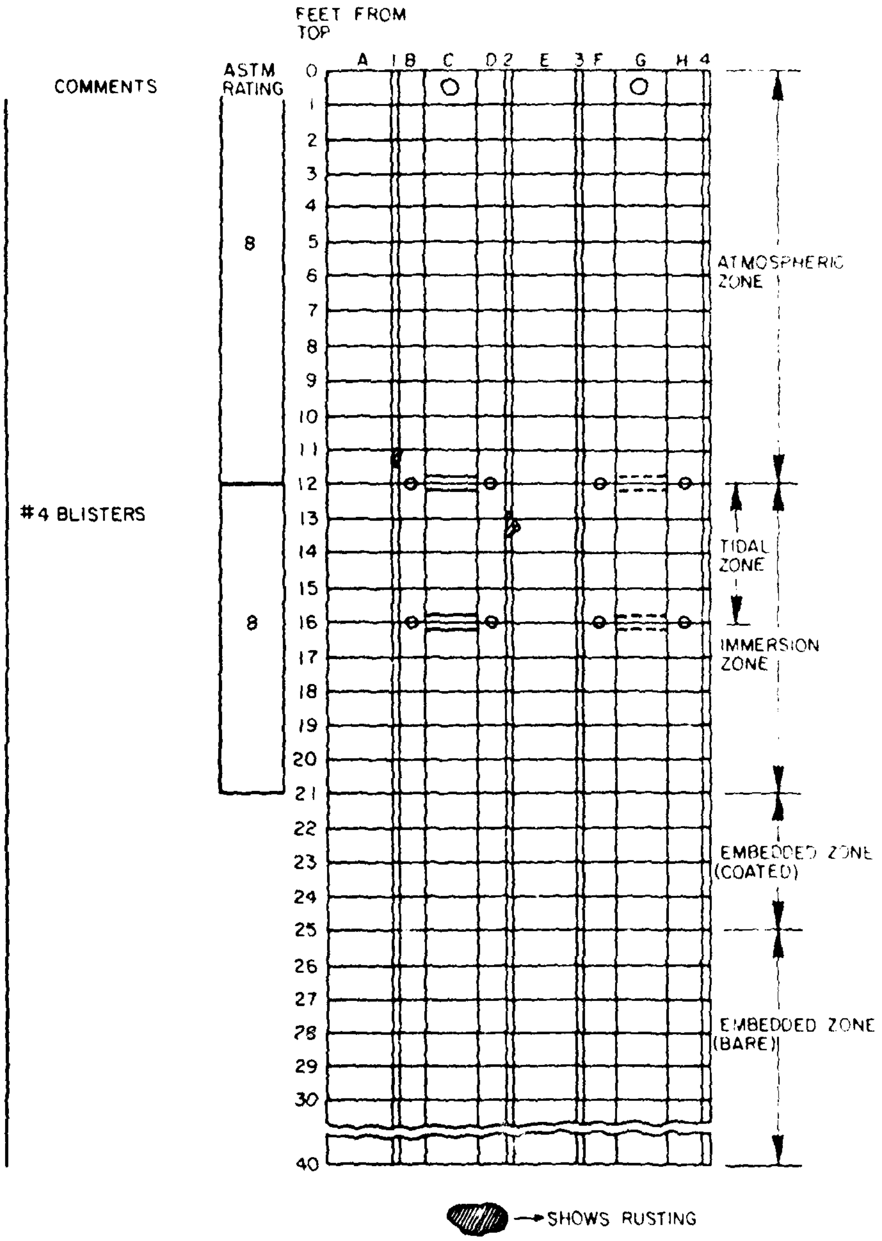
PILE NO 19C (PILE BENT BY ICE)

COATING: FLAME SPRAYED ZINC WITH COAL TAR EMULSION



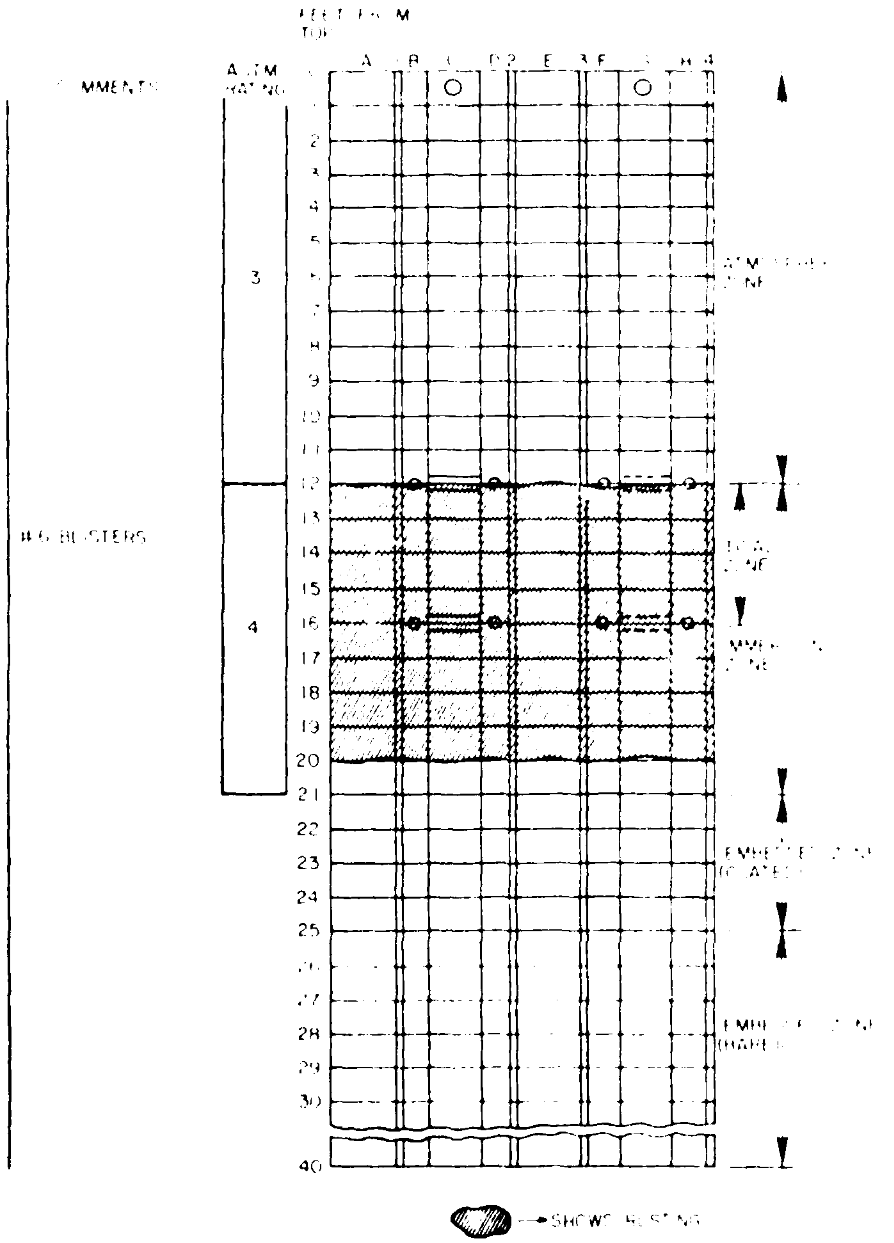
PILE NO 20C (PILE BENT BY ICE)

COATING: VINYL GLASS FLAKE OVER VINYL ZINC RICH



PILE NO 21C

COATING VINYL MASTIC OVER RESIN



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